TECHNICAL SERVICE CENTER
Denver, Colorado

UNDEPLETED NATURAL FLOW OF THE UPPER KLAMATH RIVER

Final Draft Text for Review

Prepared by
Water Resources Services
Water Supply, Use, and Conservation Group
D-8520, Technical Service Center
Denver

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A Wocus Marsh. Photo and color by T. Perry.

Undepleted Natural Flow of the Upper Klamath River

Natural Inflow to, Natural Losses from, and Natural Outfall of Upper Klamath Lake to the Link River and of Lower Klamath Lake to the Klamath River at Keno

BOR Technical Service Center
Denver

Water Resources Services
Thomas Perry, Hydrologist
Ty Mull, Hydraulic Engineer
Amy Lieb, Hydrologist
Alan Harrison, Environmental Engineer

Concrete Dams and Waterways
Elisabeth Cohen, P.E., Hydraulic Engineer

BOR Klamath Area Office
Klamath Falls

John Rasmussen, Hydrologist
Jon Hicks, Water Conservation Specialist

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This report was prepared for
Dave Sabo
Area Manager
Klamath Area Office
Klamath Falls, Oregon

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Contents –

[Note: Elements currently in progress are indicated in colored `Lucida Console` font, as shown in the preceding. These elements will be included in the final report.]

Preface

In 2001, the Bureau of Reclamation released an initial report of hydrodynamic modeling of Upper Klamath Lake. The modeling was redone for Reclamation by Philip Williams & Associates with data provided by Reclamation in October of 2002. The scope of the PWA modeling was very limited due to the data readily available for use within the short period of time needed to complete the model. Therefore, in December of 2002 Reclamation began work on the current study in order to obtain a more representative estimate of the effects of agricultural development on natural flow in the upper basin. This study and its simulated flows supersede any previous modeling by including a large body of data, not included in the previous Reclamation study, yet critical to assessing the natural hydrology of the upper basin.

A draft of this report was released for review and comment in December, 2003. Based on the received comments the report was re-organized, and additional explanation and elements have been included. Some aspects of the study regarding received comments are currently in progress.

Executive summary

A monthly natural flow history was determined for the 1949 to 2000 period at the Keno gage of the Upper Klamath River basin in south-central Oregon. Included within the evaluation is an assessment of natural flows for the same period at the outfall of Upper Klamath Lake, which forms the head of the Link River at Klamath Falls, Oregon. Flow past the Link River gage is tributary to the Klamath River above Lower Klamath Lake. These natural flows were determined using standard and accepted methods. Records used in developing this analysis were derived from stream-gaging records and from climatic records for stations within and adjacent to the study area. Information was also obtained from published maps and reports, and file documents of the Klamath Area Office. Currently, received comments are being addressed and evaluation of elements related to these comments is in progress.

The objective of this report is to provide a representative *estimate* of the monthly natural flow of the Upper Klamath River. Such an estimate is of the natural flow that would typically have occurred without the water-resources developments in the Upper Klamath Basin. A water-budget assessment was used in the determination of the natural flows. The assessment includes results from an evaluation of present-day irrigation depletions, and losses from reclaimed marshland, that have changed the natural inflow to, and resulting natural outfall from, Upper Klamath Lake. Also evaluated were losses to the natural inflow that would have been incurred due to pre-development marshland and evaporation associated with Upper Klamath Lake. The natural outfall from the lake comprised the natural flow of the Link River at Klamath Falls and also the consequent natural inflow to Lower Klamath Lake. Therefore, a similar evaluation was also completed for Lower Klamath Lake to estimate the natural flow of the Klamath River at Keno. The water-budget assessment was designed to simulate each lake as a natural water body within a stream-connected two-lake system. Much of the assessment was completed using Excel.

Results of the presently incomplete assessment indicate the following natural water balance for Upper Klamath Lake:

Average annual natural inflow………………………..	1,668,000 ac-ft
Average annual natural net loss ……………………...	244,000 ac-ft
Resulting average annual natural outfall..……………	1,424,000 ac-ft

For Lower Klamath Lake the natural water balance for the outfall at Keno was noted as follows:

Average annual natural inflow………………………..	1,496,000 ac-ft
Average annual natural net loss ……………………...	188,000 ac-ft
Average annual overflow, Lost R. Slough …………...	6,000 ac-ft
Resulting average annual natural outfall..……………	1,302,000 ac-ft

For the natural system above the Keno gage, the estimated net loss due to evaporation and marsh evapotranspiration averaged about 432,000 ac-ft annually.

Materials and data researched and used –

Supporting information used in this study included documents from archives of the U. S. Bureau of Reclamation Klamath Area Office, numerous USGS Water Supply Papers regarding stream-gaging records, and compact-disk databases containing digital records of gaged flow, lake stage records, and meteorological data. Many of the anecdotal items reviewed were from newspaper articles or clipped from magazines and consisted of information presented in narratives of past events or conditions, transcripts of interviews, newspaper accounts, books, diaries, and historical journals. These provide an impression of pre-project conditions which can be an adjunct to the empirical and scientific information gleaned from other sources. Reviewed materials also included unpublished and out-of-print scientific reports, historical maps, letters, books, journals, and photographs.

Past watershed and lake conditions were obtained through searches of the USBR Klamath Basin Area Office archives, the Shaw Historical Library at the Oregon Institute of Technology, the Klamath County Museum, USGS, and OWRD. Current watershed conditions were ascertained through file records and other information available from the USBR Klamath Basin Area Office. Useful information regarding irrigation practices, land use and streamflow was also obtained from USGS and OWRD records. The information was used as an aid in constructing, calibrating, and verifying the spreadsheet model. Field reconnaissance was also undertaken to verify current field conditions. A detailed examination of the field area was completed for the Wood River Valley in early August, 2002. At this time, the major portions of the field area of the Sprague and Williamson watersheds were also examined.

Study elements and methods –

Several basic elements considered in the study. Foremost, how had development altered the system. Second, was there information available regarding conditions existing before these changes occurred. Finally, was there useful data that would assist in the estimation of changes to the natural system. To accomplish this, the following were completed:

1) *Evaluation of pre-development conditions above the Link River gage –*
2) *Evaluation of pre-development conditions from the Link River gage to Keno –*
3) *Simulation of Upper and Lower Klamath Lakes as natural water bodies –*

The integration of temporal and spatial data resulted in individual components of the water budget that were used to evaluate the undepleted natural flow of the Klamath River above Keno. A detailed evaluation of mapped irrigated areas, marshlands, and natural conditions for each of the lakes was completed. The evaluation of evapotranspiration from irrigated lands and marshlands, and evaporation from open water, used accepted methods and procedures in the determination of these elements. The temperature and precipitation driven Blaney-Criddle method was used to calculate evapotranspiration. The method easily accommodates data given in a monthly time step. Losses from irrigated fields and marshes and evaporation from the lakes was quantified. Correlation methods were used to extend existing gaging histories for the period of interest and assess discharges from watersheds already in natural condition, but having minimal gaging histories. Missing values were estimated to complete the meteorological data records that were used.

Some gaged records, such as that for the USGS stream gage on the Sprague River near Chiloquin, were adjusted to estimate the natural flow based on a water budget for the gage. Depletions from crop irrigation and losses from reclaimed marshland were respectively added to, and subtracted from, the flow record to obtain the estimated natural flow at the gage. The resulting determined natural flow then becomes part of the inflow used in a water-budget for Upper Klamath Lake.

Natural streamflow into the Wood River Valley, and from the east flank of the Cascades, was determined by estimating the natural flow from the upland watershed portions of these streams. For streams flowing across the valley floor, attendant riparian consumptive uses that would have been a natural loss were subtracted from the inflow. The resulting estimated natural flow was then also considered an inflow to Upper Klamath Lake.

Noted changes from pre-development conditions –

The present-day watershed tributary to Upper Klamath Lake is different than that existing under pre-development conditions. The most extensive changes include development of irrigation and grazing, and other changes such as the presence of roadways, channelization of streamcourses, clearing of land for grazing, clear-cutting for logging, and other changes. Many changes may have produced an impact that is difficult to quantify. Other changes were significant.

The Wood River Valley has been extensively reclaimed for pastureland. Streams flowing into the valley have been extensively re-channeled and diverted for flood irrigation. Natural riparian marshes and stands of water-loving trees are mostly gone except for those noted presently along Crooked Creek, Fort Creek, and in the vicinity of Wood River Springs. Numerous wells penetrating the basin-fill produce artesian ground water from a regional basalt aquifer that is under confined conditions. This water is also used for irrigation, some stock watering, and other uses. However, before development, the Wood River Valley most likely appeared as a grassland prairie with ground-water seeps and wetlands scattered along the valley floor. A woodland crossed the northern end of the valley floor. Streams flowing into the valley from the Cascades and Mount Mazama, as well as from springs along the eastern valley wall, probably had attendant riparian marshes supporting sedges and rushes. These riparian areas likely had stands of water-loving trees and shrubs.

Natural riparian systems were likely present also along the streamcourses of the Sprague and Williamson Rivers similar to those for the pre-development condition of the Wood River Valley. Development of irrigated land and other changes like those in the Wood River Valley are noted along the Sprague. Much of the marshland and valley-bottom wetland in the vicinity of the towns of Beatty and Sprague River has been reclaimed and is irrigated. Water is diverted from the Sprague just above its confluence with the Williamson River for irrigation of land on the Williamson delta adjacent to Upper Klamath Lake. Farther upstream along the Williamson, there are few changes in the stream reach below Klamath Marsh. Although some of the wetlands of Klamath Marsh have been drained and reclaimed, much of the irrigation in the upper Williamson takes place above Klamath Marsh. Within the Sprague and Williamson watersheds, and especially that of the Sprague, numerous wells also pump from the confined regional aquifer.

Other noted changes include clear-cutting for timber harvest, land clearing for pasture and ranching, suppression of fire in forested areas, and the consequent invasion of juniper. Extirpation of beaver, channelization and diking of streamcourses for flood control and land reclamation, and roadway encroachments, have consequently reduced detention of streamflow and changed the character of stream baseflow from that under natural conditions.

Changes noted to Upper Klamath Lake –

Although certain aspects of Upper Klamath Lake appear today much as they did prior to the 20th century, the lake has changed considerably from that existing under natural conditions. The construction of dikes has established a new perimeter for the open-water surface of the lake and has permitted reclamation of much of the lake floor in the shallower portion of the lake. The combination of dikes, reclamation of marshland, and the regulation of the outfall, has fundamentally changed the hydraulic performance of the lake. An evaluation of these changes and conceptual definition of the pre-development lake was necessary to understand how the lake performed as a natural water body in response to the natural inflow to the lake.

Changes noted to Lower Klamath Lake –

Lower Klamath Lake was documented by a very detailed planimetric survey completed by the U.S. Reclamation Service in 1905. Very nearly all of the pre-development aspect of the lake, and its marshlands, was still in place at that time. Today, all of the natural lake has been reclaimed for irrigation except for the preserved wetland area in the Lower Klamath National Wildlife Refuge.

Prior to development, Lower Klamath Lake was a shallow water body averaging less than 5 or 6 feet in depth. The broad, wetland marsh surrounding the central, open-water area of the lake, was growing in very shallow water that had little depth near the lakeshore. The greatest expanse of open water was resident in the deeper, southern portion of the lake where evaporation made the lake moderately alkaline. This alkalinity was probably a factor limiting the growth of bulrush within that part of the lake. Inflow to the lake was from backwater overflow of the Klamath River and through the bulrush wetland adjacent to the river. Inflow from the Klamath also came into the lake through the naturally deep channel of the Klamath Strait. Along the Klamath River, the Keno reef at an elevation of about 4083 ft (USRS elevation datum) provided the backwater control for this inflow. During the most typical years, the stable water-surface elevation for the lake was probably about 4084 to 4085 feet, more or less. However, evidence suggests that during years of high snow-melt inflow, the water-surface elevation of Lower Klamath Lake may have exceeded 4088 feet for a considerable time. Under these conditions, much of the lake would have appeared as open water and high-water overflow of storage through the Lost River Slough would have been considerable, perhaps exceeding 800 to 1000 cfs during such times. The Lost River Slough was closed with a dike in 1890.

In 1905, the reclamation of Lower Klamath Lake began for recovery of the land to agricultural uses. By 1917, with closure of the Klamath Strait, the ending phase was initiated in draining the vast area of open water and marshland of Lower Klamath Lake. Over the intervening time to the mid-1950s, the dry lakebed of Lower Klamath Lake was extensively reclaimed for irrigated agriculture and this reclaimed area is part of the Klamath Project operated by the U.S. Bureau of Reclamation. However, a part of the former lake is maintained as a natural area, which is the Lower Klamath National Wildlife Refuge.

Evaluation of the natural flow at the Link River and Keno gages –

To evaluate the effect of these natural lakes on the inflow, storage, and depletion of the natural inflow to them, a flow routing scheme was used to simulate each lake as a natural water body. The natural outflow from Upper Klamath Lake would become the natural inflow to Lower Klamath Lake. Assessment of several factors related to predevelopment condition of the lakes was required to determine the natural flows. These factors are as follows:

1) Estimation of the predevelopment extent of the open-water surface area of the lake.
2) Estimation of the predevelopment extent and condition of natural marshlands attendant to the lake.
3) Estimation of the storage capacity of the natural lake.
4) Evaluation of the hydraulic response of the outfall from the lake due to storage-induced changes in water-surface elevation.

For a natural lake flow-routing scheme, lake inflow would be depleted by open-water evaporation and marsh evapotranspiration and the remainder, or net inflow, would be stored thereby increasing the water-surface elevation of the lake. Outfall from the lake is calculated from this water surface elevation, and this outfall is then concurrently removed from the balance of storage within the lake. The water-budget simulation developed for these lakes assumes that the evaluation of these foregoing factors is adequate and representative of processes that actually occurred.

Results -

For the present status of the assessment, the average annual inflow, loss, and outfall for the period of interest from 1949 to 2000 is noted as follows:

Upper Klamath Lake:

Inflow:

Williamson River …………………………. 910,000 ac-ft
Wood River Valley ……………………….. 488,500 ac-ft
Ground-water inflow ……………………… 271,000 ac-ft

Loss:

Marsh evapotranspiration ………………….. 85,200 ac-ft
Evaporation ……………………………….. 158,500 ac-ft
Overflow, Lost R. Slough …………………… 6,000 ac-ft

Resulting natural outfall, Link R. gage ..…………1,424,000 ac-ft

Lower Klamth Lake:

Inflow:

At Link River gage ……………………… 1,424,000 ac-ft
Ground-water inflow ……………………….. 72,400 ac-ft

Loss:

Marsh evapotranspiration ………………….. 96,000 ac-ft
Evaporation ………………………………… 92,000 ac-ft

Resulting natural outfall, Keno gage ...…………... 1,302,000 ac-ft

Address of comments and elements in progress –

This study was initially released for review in early December, 2003. Received comments discussed specific aspects of the study that needed to be expanded. These aspects are related unmeasured ground-water inflow into Upper Klamath Lake, expanded assessment of Klamath Marsh and Sycan Marsh, assessment of changes in forest conditions and consequences to natural flows, sensitivity analysis, and extension of the flow histories, among others. Other aspects having similar considerations were seen by the seven investigators preparing the natural flow study. These considerations are related to possible climate-signature adjustment of ground-water discharges into the headwaters of streams in the Wood River Valley, continued internal quality control and data validation, and comparison of natural flows developed in this study to other nearby natural flow histories, and to the present-day gaged-flow history of the Klamath River.

Currently, the ground-water inflow assessment regarding Upper Klamath Lake has been evaluated and the results of that investigation are included within this report. Other aspects regarding ground water remain to be addressed. Background material has been researched and reviewed regarding several other issues that comments requested be addressed. Current standing of some of these issues, and summaries of some background information related to these areas, is provided in Part 4 of this report.

Part 1: General Overview

Introduction –

This report presents detailed aspects of the investigation and results in estimation of the undepleted natural flow of the Klamath River at Keno. In its most abstract sense, the objective of this report is to present a representative *estimate* of the monthly natural flow of the Upper Klamath River as such flow would have occurred without the water-resources developments for irrigation of crops in the Upper Klamath Basin. This was determined by using a water-budget assessment of the watershed as a natural system. Therefore, this representative estimate also includes the requisite assessment of the natural inflow to Upper Klamath Lake, of the natural flow at the outlet of Upper Klamath Lake into the Link River at Klamath Falls, and of the resulting natural flow at the outlet of Lower Klamath Lake to the Klamath River at Keno. To objectively achieve the determination, an evaluation was completed of present-day irrigation depletions and losses from reclaimed marshland that have changed the natural inflow to, and resulting natural outflow from, Upper Klamath Lake. This included an evaluation of losses to the natural inflow that would have been incurred due to pre-development marshland and evaporation associated with the pre-development aspect of Upper Klamath Lake. Also required was a similar evaluation of the pre-development aspect of the Lower Klamath Lake and losses that would have been incurred to the natural flow of the Klamath River at Keno. The study related to the scope of the investigation and determination of the natural flow of the Klamath River is currently in progress.

The period of record considered in this investigation is from 1949 to 2000, a period of 52 years. This period of record was chosen due to limitations regarding pre-1949 data. Methods used in evaluation of the natural flow for the Link River are described. The area of study for the total scope of this investigation is the Klamath River basin above Keno, Oregon. The locations of the Link River and Keno gages are shown in the general watershed map for the upper Klamath River, *Figure 1*.

Results of the water-budget assessment were accomplished using Excel, a sophisticated spreadsheet available in the Microsoft Office for Windows software package. The results are given as the determined natural flows for two important *stream gages*, one located on the *Link River at Klamath Falls* and the other on the *Klamath River at Keno*. Also, the monthly average water-surface elevations under natural conditions are given for each of the lakes. Many supporting and intermediate work-products using Excel were also developed to assist the evaluation of irrigation net consumptive uses, marshland net evapotranspiration losses, and the storage, surface area, and hydraulic performance characteristics of the lakes. Excel was also used extensively in the evaluation of natural streamflows for the Wood River Valley portion of the study area. Other specially developed digital tools were used in the primary evaluation of evapotranspiration and in the correlation analysis used to reconstruct missing data in meteorological and streamflow records.

[The water budget developed in Excel is really a numerical simulation based on a detailed month-to-month water budget of processes occurring in Upper and Lower Klamath Lakes. This spreadsheet, **ukl.lkl_simulation**, which is also a separate part of this report, is clearly labeled and documentation is provided in Appendix 2-X. The precision of the values reported on the **calculations** tab of this spreadsheet, and other tabs, exceeds the reliable accuracy of the estimates.]

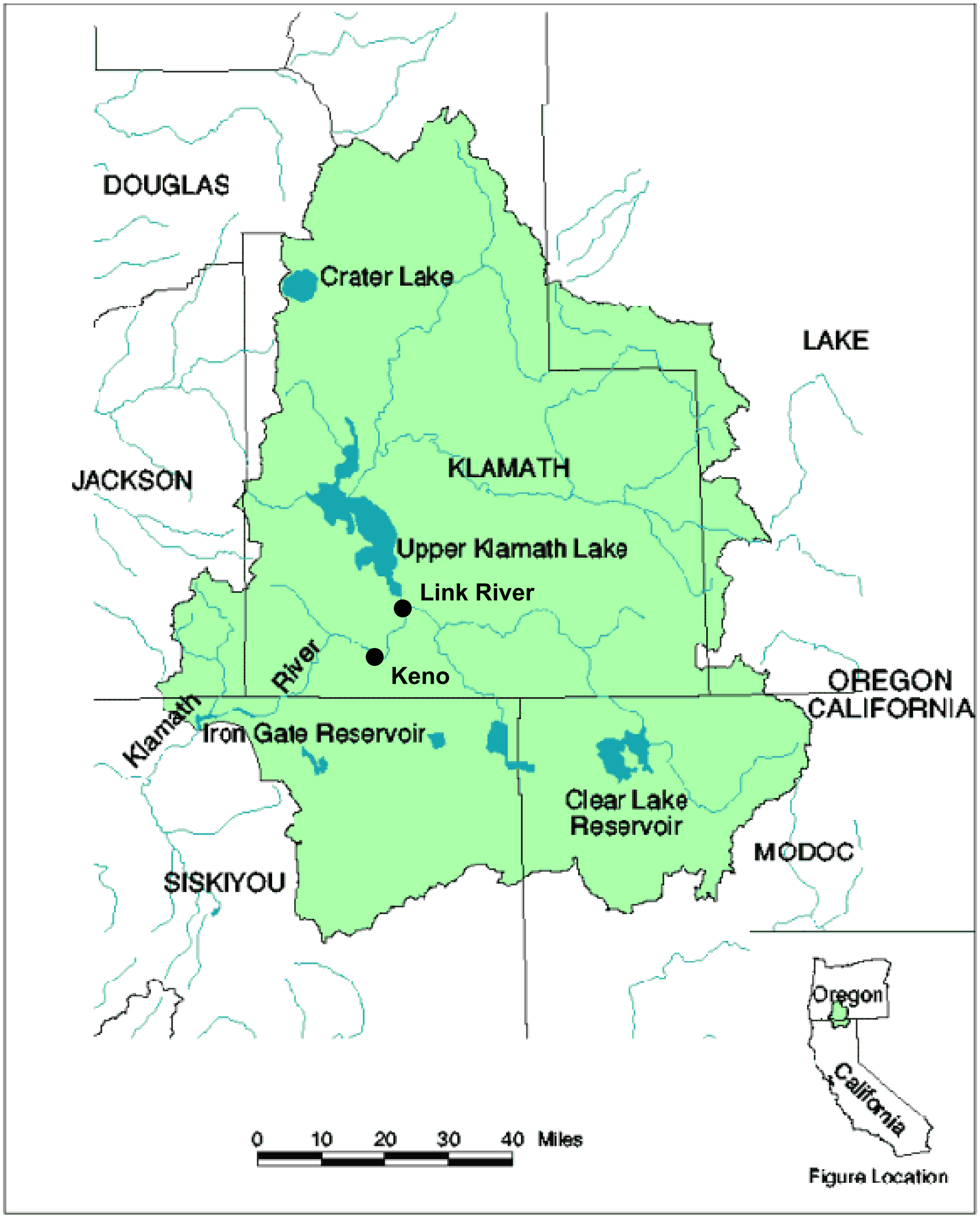

Figure 1. General area map showing the upper Klamath River watershed and location of the Link River and Klamath River at Keno gaging stations.

Study objective –

For the Upper Klamath River, there have been many issues related to effects of changes of land use, changes of channel condition, and irrigation developments in the upper basin, particularly in relation to the operation of the Klamath Project. Within the historical period of development of these uses and changes in the upper basin, there have been no studies to assess the total impact to the natural flow of the stream and estimate, thereby, the undepleted natural flow of the Upper Klamath River. Having a basis for examination of this estimated natural flow allows examination of specific questions regarding the impact of development to the stream and of changes in present-day conditions and their affect on the flow of the stream.

The subject and motivation for this natural flow study, however, is simply to develop a representative and scientifically objective estimate of the undepleted natural flow of the Upper Klamath River. In general, the problem being addressed in this investigation is straightforward, namely, determine the undepleted natural flow of the Upper Klamath River by assessment of the factors that are necessary to evaluate the depletions and other alterations to the natural flow. The undertaking of this assessment cannot adjust for every development or alteration in the watershed, but can reasonably account for those factors having the greatest impact. Further, the assessment must attempt to account for unseen factors that affect of alter the natural flow.

Results –

For the given period of record, 1949 to 2000, the resulting water balance for Upper and for Lower Klamath Lake was determined. The consequence of this water balance is the resulting natural outfall from each of these lakes. For Upper Klamath Lake, the following estimated water balance and outfall at the Link River gage was noted:

Average annual natural inflow……………………….. 1,668,000 ac-ft
Average annual natural net loss ……………………... 244,000 ac-ft

Resulting average annual natural outfall..…………… 1,424,000 ac-ft

Similarly, for Lower Klamath Lake, an accounting of the inflow to the lake and losses provides the water balance for the outfall at Keno. For Lower Klamath Lake, the following estimated water balance accounted at the Keno gage was noted:

Average annual natural inflow……………………….. 1,496,000 ac-ft
Average annual natural net loss ……………………... 188,000 ac-ft
Average annual overflow, Lost R. Slough …………... 6,000 ac-ft

Resulting average annual natural outfall..…………… 1,302,000 ac-ft

For the natural system above the Keno gage, the estimated net loss accounted for natural lake evaporation and marsh evapotranspiration averaging about 432,000 ac-ft annually.

<u>Study elements</u> –

Completion of the study required an assessment of changes to the natural system above the Keno gage. This included an evaluation of changes to Upper Klamath Lake, irrigation developments in the Wood River, Sprague River, and Williamson River watersheds, and of changes to Lower Klamath Lake. Several basic elements had to be considered. Foremost, how had development altered the system being evaluated, and secondly, was there information available regarding conditions existing before these changes were implemented. Finally, was there useful data that would assist in estimation of changes to the natural system.

Evaluation of pre-development conditions above the Link River gage –

An evaluation of irrigation developments in each of the major tributary watersheds to Upper Klamath Lake indicated that for two of the watersheds, the Sprague and Williamson Rivers, alterations to natural flow could be evaluated by estimation of irrigation depletions that were incurred. An assessment was therefore completed to determine the extent of agriculturally developed land where water was diverted for irrigation. Because natural marshlands had, in some instances, been reclaimed for irrigation, natural depletions that would have been incurred by these marshlands were also estimated. The net sum of these depletions was then added to the appropriate gaged recorded flow to restore the flow record to estimated natural flow. This result was then used as a natural inflow element to Upper Klamath Lake.

The evaluation of the Wood River Valley did not use this method, however. Accounting for the complex interaction of irrigation with the ground-water system of the Wood River Valley was obviated by determining the natural inflow to the valley and subtracting from that inflow the natural loss that would have been incurred before inflow to the lake. Natural flows were estimated and natural losses similarly accounted for streams along the east flank of the Cascades, most of which are tributary to Sevenmile Creek. Natural losses to the Wood River and the other streams were estimated based on the evaluation of recently acquired infrared ortho-photography of the Wood River Valley, or other ortho-photographic images or satellite images.

Changes to the natural condition of Upper Klamath Lake were evaluated in a manner similar to the Wood River Valley. Prior to 1890, plane-table surveys of areas comprising 1:250 000 scale quadrangles covering Upper Klamath Lake had been completed by the U.S. Geological Survey. An updated compilation of these quadrangles was published in 1906 by the U.S. Reclamation Service. Maps from both of these sources were used to determine the extent of the open-water surface area and identify natural marshlands and other changes associated with pre-development conditions for Upper Klamath Lake. Evaluation of the lake was then completed by a water-budget assessment of the lake as a natural water body and included the estimated ground-water inflow to the lake from the regional aquifer. The natural flow of the Link River was computed as the resulting natural outfall from Upper Klamath Lake.

In essence, the estimated natural flow of Link River was determined by accounting for changes to the inflow and outflow of Upper Klamath Lake that resulted from alterations to pre-development conditions. Trends in development, such as expansion of irrigated acreage over the period of interest for the study, 1949 to 2000, were not included. Inclusion of these trends, provided that sufficient and reliable data were available, would likely result in decreased natural flows for the earlier years represented in this study. Further, not all changes to the watershed could be reasonably addressed in determining the estimated natural flow of Link River. Potentially significant factors not evaluated include effects of fire suppression, beaver extirpation, stream channelization for flood control, roadway embankments and drainage, and juniper encroachment, among others. A detailed assessment of these factors is generally beyond the scope of this study.

Evaluation of pre-development conditions, Link River gage to Keno –

The determination of natural flow at Keno had similar requirements to those for evaluation of Upper Klamath Lake and the natural outfall to the Link River. A detailed evaluation irrigation development for Lower Klamath Lake was obviated because in 1905 the U.S. Reclamation Service had completed a detailed planimetric survey of these project lands, all of which were within the *yet undeveloped* natural ecosystem associated with Lower Klamath Lake *just above* the gage on the Klamath River at Keno. The determination of the natural flow at Keno therefore required an assessment of Lower Klamath Lake and evaluation of the natural depletions to the undepleted natural inflow coming from the outfall of Upper Klamath Lake. Because the area mapped in 1905 comprised the entire interactive pre-development hydrologic system associated with Lower Klamath Lake and the natural outfall of the Klamath River at Keno, an evaluation of the mapped marshlands and open-water surface areas that were associated with the undeveloped area of Lower Klamath Lake was therefore completed. The determination of the natural outfall of the Klamath River at Keno was accomplished using a water-budget assessment of Lower Klamath Lake and the associated hydrologic system. Elements that were assessed included depletions from pre-development marshlands associated with the inundation area of Lower Klamath Lake, interactive storage with Lake Ewauna, and overflow discharges that occurred naturally through the Lost River Slough.

Simulation of Upper and Lower Klamath Lakes as natural water bodies –

Implementation of a water budget for Upper and Lower Klamath Lakes required developing information about 1) the storage and inundation surface area characteristics of these lakes, and 2) the discharge characteristics at the outfall point of the lakes. These characteristics were evaluated in relation to the elevation, or stage, of the water surface of each lake. Lake stage is given as the gage height reading of the water surface. Additionally, discharge from each lake was also related to the gage height of the water surface. Therefore, with definition of the needed characteristics, the hydraulic performance of each lake could be simulated in a month-to-month water budget that accounted for natural inflow, storage of water within the lake, resulting estimated gage height of the water surface, and discharge from each lake. In addition, ground-water discharge to the lake from the regional aquifer was noted as related to gage height of the water surface. The characterization and inclusion of this ground-water discharge comprises a critical additional element currently being evaluated for the study.

An overview of methods used –

The integration of temporal and spatial data results in the individual components of the water budget that were used to evaluate the undepleted natural flow of the Klamath River above Keno. The evaluation of evapotranspiration from irrigated lands and marshlands, and evaporation from open water, required the use of accepted procedures in the determination of these elements. Losses from irrigated fields and marshes and evaporation from the lakes must be quantified for a water budget accounting of processes. Discharges from watersheds already in natural condition, but having minimal gaging histories, must have those gaging histories extended to cover the period of interest. Meteorological data records having missing values must have those missing values restored. The following subsections describe methods that were applied in the analysis of data and development of results, the restoration of missing data, and the application of these data and results to the water budget of the lakes.

Crop and marshland net evapotranspiration determinations –

The Blaney-Criddle method was used for determinations of net evapotranspiration, or net et, from crops, marshlands, and riparian zones. Details regarding the calculations and use of the method are given in Appendix 1-1X. The method is empirical and uses crop coefficients that have been determined and are published for the field areas or regions being addressed in the net et determinations. Data requirements to use the method for estimating water uses by irrigated lands are as follows:

1. Location of irrigated lands being irrigated.
2. Types of crops and number of acres for each crop within these lands.
3. Diversion records, if available, and knowledge of water use practices.
4. Monthly precipitation and monthly average temperature for the area being addressed.

Location of irrigated lands and acreages were provided from mapped coverage generated by the OWRD. Types of crops were evaluated based on field examination, reports of the Bureau of Reclamation, and local knowledge in the Klamath Projects Office regarding cropping practices within the areas addressed. Although diversion records were not available, water use practices were observed and diversions (specifically for the Modoc Canal) were estimated based on the water needed to meet an irrigation requirement for an irrigation application efficiency assumed to be about 65 percent. Climatological data was acquired from the data sources mentioned previously.

Data requirements to use the method for marshlands and riparian areas are as follows:

1. Location of marshlands.
2. Type of plant community or vegetation within these marshlands or riparian areas.
3. Knowledge of seasonal factors that may affect marsh and riparian et.
4. Monthly precipitation and monthly average temperature for the area being addressed.

The determination of water uses requires supporting input data to be a *continuous* time series for the period of interest being examined. Supporting input data generally consists of the time series for the meteorological data noted in item 4. Annual variability in acreages may be addressed by calculating water use for a designated *type acre* that is specific to the land area being evaluated, and calculating water use for year-to-year acreages. This approach is also helpful in adjusting estimated results based on updated changes in total acres, or to accommodate other changes that have been noted. Results of the water use determined using the Blaney-Criddle method are then integrated into a water budget for each specific area, as needed.

Crop net evapotranspiration is termed in this study as crop net consumptive use and may be defined as potential crop evapotranspiration less effective precipitation. For marshland, this same definition applies. Marshland net evapotranspiration is simply the potential evapotranspiration that may occur from the marsh less effective precipitation. Because not all precipitation is sufficient to offset potential evapotranspiration, only the part that is effective in doing so is considered.

Calculation of lake open-water surface evaporation –

The Hargreaves equation was used to calculate an estimated evaporation incurred by lake open-water surface areas. Details regarding the calculations and use of the method are given in Appendix 1-2X. The estimation is based solely on air temperature and knowledge of the latitude of the site, i.e. meteorological station, being evaluated. These data are generally available whereas pan-evaporation data at these stations is not generally available. The equation therefore gives an estimate of evaporation based on the evaporation potential related to temperature, and energy provided by incoming solar radiation at the latitude of the site being evaluated. The resulting calculated monthly evaporation in feet is applied to specific open-water surface areas to determine monthly lake evaporation. Data requirements for use of the equation are as follows:

1. Daily maximum and minimum air temperature data, if available, or an estimate of these data from monthly values if daily values are unavailable.
2. Latitude of the site for which evaporation is to be estimated.
3. Monthly precipitation for the site being evaluated.
4. Area in acres of open-water surface for which evaporation is to be estimated.

The calculated daily evaporation is accumulated monthly and given as an open-water surface evaporation rate in inches, or feet. The result is validated by comparison of the calculated monthly Hargreaves evaporation with concurrent monthly pan evaporation data at a site nearby or the same as that for which open-water surface evaporation has been calculated. Results may also be compared on a daily basis with Kimberly-Penman evaporation from an AgriMet station that is nearby the site for which Hargreaves evaporation has been computed. Hargreaves evaporation was adjusted by the appropriate pan coefficient to give the estimated evaporation rate from the open-water surface area at the site of interest. This was accomplished by comparison of the calculated evaporation with concurrent measured pan evaporation at the Klamath Falls Agricultural Experiment Station. The calculated evaporation was then adjusted by the appropriate pan coefficient that was determined in the comparison. With the inclusion of monthly precipitation data at that site, the open-water surface evaporation is adjusted to the net evaporation rate by subtracting the precipitation from the estimated evaporation. In some instances, the net evaporation is noted as being negative thereby indicating a precipitation accrual to the open-water surface at the site of interest.

Adjustment of gaged flow records to undepleted natural flow –

Flow records, such as those for the USGS stream gage on the Sprague River near Chiloquin, may be adjusted to natural flow based on a water budget to restore the gage. The water budget for natural flow at the gage is straightforward:

natural flow = gaged flow + crop net consumptive use – reclaimed natural marshland net evapotranspiration

Of usual consequence to this type of water budget would be irrigation return flows that are delayed in returning to the stream. Because the Sprague and Williamson Rivers do not have well developed and transmissive valley-fill alluvial aquifers, and because most of the irrigation diversions from these streams irrigate land that is in proximity to the stream, irrigation return flows may be considered due to field runoff from flood irrigation and not drainage to the stream of irrigation percolation losses that recharge a ground-water reservoir hydraulically connected to the stream. These return flows, therefore, are already reasonably accounted at the gage and would have been considered a factor in diversion from the stream and irrigation of crops if otherwise delayed by ground-water drainage to the stream. The net impact to the gage is from the net consumptive use incurred by the crops being irrigated as this is the amount of diverted and applied water that is lost and not appearing at the gage. The resulting natural flow that is determined becomes part of the inflow used in a water-budget for the natural lake.

Restoration of missing data from records of monthly streamflow and climate data –

Correlation analysis was used to restore missing values from monthly-value data records used in this study. Details regarding the calculations and use of the method are given in Appendix 1-3X. The method is fundamentally different than linear least-squares estimation, also known as regression analysis. Both methods compare two data groups where one data group, the dependent variable or y-data group, is being compared to another group, the independent variable or x-data group. Regression analysis is restricted by assumptions that are applied regarding the relationship of data elements that are being compared. The basis for the estimation assumes the y-data elements are dependent on error free and x-data elements that are independent of y-data. Correlation analysis makes no such assumption even though there are many instances where least-squares line-fitting procedures are used in the comparison of the data groups. Regression analysis provides a predictive model wherein the estimates of y values that are obtained are the most precise unbiased estimates that are linear functions of the x values. However, there is no theoretical or predictive model being defined by correlation analysis. In correlation analysis, the line of relation fitted to the xy-data grouping may be linear or curved, as needed, to describe the observed relationship. Missing values in the y-data group are calculated from the correlation line by using the concurrent value noted in the x-data group.

Estimating streamflow from ungaged watersheds –

Monthly flow records are noted as sparse for streams heading on the east flank of the Cascades and flowing into the Wood River Valley or Pelican Bay area of Upper Klamath Lake. Details regarding the methods that were used are given in Appendix 1-4X. Although many of these streams have had miscellaneous (or incidental) flow measurements made from time to time, there are no continuous streamflow records for these streams for the period of interest. Some of these streams have been gaged from as little as less than three to, in some cases, more than twelve years. Therefore, estimation of the needed portion of these flow records was completed as follows:

1. Obtain all available gaged data, including any miscellaneous, instantaneous streamflow measurements, and
2. Determine how natural these data are. If necessary, remove diversion effects.
3. Determine similarities between the Cascade - Wood River Valley tributaries and gaged streams nearby based on geology, hydrograph shape or prominent flow regime, and baseflow characteristics.
4. Develop total monthly flows for gaged periods by relating instantaneous flow measurements to at least 2 other concurrent daily gaged records.
5. Relate monthly total discharges to those that are concurrent from a nearby, similar gage with longer period of record.
6. Create a synthetic natural time series based on monthly total flow correlation equations.

For other streams, uniqueness of the watershed or flow characteristics that may be observed required specific assessment based on specially adapted techniques that were used only for those individually developed flow records. As an example, temperature and precipitation data were not used in the standard process, however these data were integral in estimation techniques employed for unique watersheds, such as Annie Creek and Denny Creek. Natural flow histories are required the ungaged watersheds to assess the natural inflow to Upper Klamath Lake.

<u>Scope of materials researched and reviewed</u> –

Supporting information used in the development of this study included a host of documents from archives of the Klamath Area Office, numerous Water Supply Papers regarding stream-gaging records of the United States Geological Survey, compact-disk databases containing digital records of gaged flow and lake stage records, and of meteorological data. Many of the items reviewed were from newspaper articles or clipped from magazines. As such, much of this material was anecdotal consisting of information presented in narratives of past events or conditions, such as transcripts of interviews, newspaper accounts, books, diaries, and historical journals. Examples of sources of anecdotal information include the Shaw Historical Library's journal "Klamath Echoes," the "Klamath Republican" and "The Evening Herald and News" newspapers, and sections of "50 Years on the Klamath" by JC Boyle. By reviewing a wide variety of anecdotal sources, an impression of pre-project conditions is gained which can be an adjunct to the empirical and scientific information gleaned from other sources. Past watershed and lake conditions were obtained through searches of the USBR Klamath Basin Area Office archives, the Shaw Historical Library at the Oregon Institute of Technology, the Klamath County Museum, USGS, and the State of Oregon Water Resources Department.

Reviewed materials also included unpublished and out-of-print scientific reports, historical maps, letters, books, journals, and photographs. Generally, this historical information can be classified as empirical (and scientific) information consisting of reports of measurable data such as lake elevations, climate, land topography and ground cover (from surveyed maps), and river stages and discharge. For instance, historical topographic maps and previous studies were used to determine the extent of marshlands around the historical natural Upper and Lower Klamath Lakes as these lakes existed at the end of the pre-development era; construction drawings helped establish the pre-project structure of the reefs at the outlet of Upper Klamath Lake and in the Klamath River near Keno; and United States Bureau of Reclamation records and USGS water supply papers provided pre-dam water surface elevations and discharges at key locations. Historical photographs are also considered empirical evidence of past conditions. Good examples are the several photographs of the Link River area prior to construction of the Link River Dam. Current conditions of the watershed were ascertained through file records and other information available from the USBR Klamath Basin Area Office. This information included water records, reports, maps and aerial photographs. Useful information regarding irrigation practices, land use and streamflow was also obtained from USGS and OWRD records. The information, which is listed in the reference listing of reviewed documents, was used as an aid in constructing, calibrating, and verifying the spreadsheet model. In addition to document reviews, reconnaissance trips were taken to verify current field conditions. A detailed examination of the field area was completed for the Wood River Valley in early August, 2002. At this time, the major portions of the field area of the Sprague and Williamson watersheds were also examined.

Within the scope of the study was the requirement to acquire of all relevant meteorological and stream gaging records of interest. These records were obtained from various sources such as the National Oceanographic and Atmospheric Administration, publications of the National Weather Service, water supply papers and other publications of the United States Geological Survey, and data from NOAA and the USGS published on compact disks by Hydrosphere, located in Boulder, Colorado. Some stream gaging records were also acquired electronically from the OWRD.

Temporal data: Meteorological and stream-gaging records used and developed in this study –

Data records recovered for use in this study include precipitation and average temperature histories in addition to hydrologic records of streamflow and lake stage. Meteorological records for precipitation were recovered from digital media and missing values researched by reviewing the published records on microfiche. Other meteorological records that were researched were retrieved from published data summaries that cover an available period of record for southern Oregon from approximately 1865 to 2003. Temperature records and stream-gaging histories were recovered from digital media and were generally not researched. All primary records were restored for missing values covering the recorded period for which data were available, and were also extended, as necessary, to bracket the period of interest within the time of interest from before about 1947, if possible, to about 2002. The recovery and extension of data was accomplished using correlation analysis. Both supportive and primary records were used to accomplish this task. However, not all records embrace the nearly 145-year period from 1865 to 2003. Meteorological records before about 1900 are difficult to recover as complete histories due to missing values. Commonly, equipment would break or fail, and would require one or two years before replacement parts were available and delivered for the repair and re-installation of broken or unusable equipment. Due to scarcity, equipment was occasionally and conveniently moved to a new location, thereby ending the continuity of the records acquired at the previous location.

Stream gaging, which did not begin until about 1905 in the upper Klamath basin, suffered some of the same consequences. In many cases, stream gaging was fraught with difficulty due to equipment malfunction and failure, or high maintenance and field calibration costs. Some gaging data collection was for individual studies or, in the priority of needs and uses, equipment was moved and new records obtained from a different location. For these reasons, many records, whether meteorological or stream gaging, are incomplete. A generally complete listing of data records is provided in lists, below.

<u>Meteorological records</u>	researched yes or no	primary or supportive /basis	climate yr period published	of record extended restored
Butte Falls 1 SE	yes-p	supportive	1909-22,40-86	
Chemult	yes-p	primary	1937-2001	1937-2001
Chiloquin, Chiloquin 1 E	yes	primary	1913-79	1948-2001
Chiloquin 7 NW	yes	primary	1980-2001	1948-2001
Crater Lake National Park HQ	yes	primary/basis	1930-2001	1932-2001
Fort Klamath 7 SW	yes	primary	1953-65	1947-2001
Fremont 5 NW	no	supportive	1918-96	
Gerber Dam	yes	supportive	1925-2003	
Keno	yes	supportive	1927-2001	
Klamath Falls 2 SSW	yes	primary, supportive	1894-2001	1908-2001
Klamath Falls Ag. Exp. Sta.	yes-p	supportive	1942-88,96-2002	
Lakeview 2 NNW	yes	supportive	1910-2001	
Lava Beds National Monument	yes	supportive	1959-2001	
Lemolo Lake 2 NNW	no	supportive	1978-97	
Malin 5 E	no	supportive	1969-2001	
Merrill 2 NW	no	primary	1949-68	1929-2000
Paisly	yes	supportive	1925-2001	
Prospect 2 SW	yes	supportive/basis	1931-2001/c	
Rocky Pt. 3 S	yes	primary	1966-75	1947-2001
Round Grove	yes	primary	1920-87	1920-2001
Sprague River 2 SE, 1E	yes	primary	1953-2001	1921-2001
Tule Lake	yes	supportive	1932-2001	
Yonna	yes	supportive	1907-48	

Note: -p = partially, /basis = basis station, /c = complete

Stream gaging station records	primary or supportive /basis	water yr period of record published/recovered (dates are approximate)	extended restored
11491400 Williamson R bw Sheep Cr	supportive	1979-92	
11493500 Williamson R nr Klamath Agency	supportive	1955-2000	
11494000 Williamson R ab Spring Cr nr Klamath Agency	supportive	1912-26/sparse	
------------ Sycan R ab Sycan Marsh	supportive-p(USFS)	1992-2000	
------------ Sycan R bw Snake Cr nr Beatty	supportive	1973-2002	
11497500 Sprague R nr Beatty	supportive	1954-92	
11501000 Sprague River nr Chiloquin	primary	1921-2000	
11502500 Williamson R bw Sprague R nr Chiloquin	primary	1918-2002	
11503000 Annie Spring nr Crater Lake	supportive	1977-2002	
11503001 Combine flw Annie Spg + dvn	supportive	1977-82	
61420301 Annie Cr nr Crater Lake	supportive-p(USFS)	1992-2002	
11503500 Anna Cr nr Fort Klamath	supportive	1922-28/sparse	
11504000 Wood R at Fort Klamath	supportive	1913-37	
11504100 Wood R nr Fort Klamath	supportive	1964-68	
61430399 Wood R at 11504000 nr Fort Klamath	supportive	1994-98/sparse	
------------ Fourmile Lk Res nr Recreation	supportive	1937-78,85,92-2002	
11504600 Cascade Cn at Fourmile Lk nr Lake Creek	supportive	1922-79, 91-2002	
11505500 Fourmile Cr nr Odessa	supportive	1912-18/sparse	
61420303 Sevenmile Cr nr Fort Klamath	primary-p(USFS)	1992-2002	1947-2002
------------ Cherry Cr nr Klamath Agency	primary	1992-2002	1947-2003
11507000 Upper Klamath Lake, stage	primary, supportive	1904-05,1905-18	
51507505 Link R total flow at Klam. Falls	primary, supportive	1904-19	
11509500 Klamath R at Keno	primary, supportive	1904-14	
------------ L Klamath Lk nr Brownell, stage	primary, supportive	1904-14	
------------ Gerber Reservoir inflow	supportive	1926-2001	
61420101 Cottonwood Cr nr Beaver Marsh	supportive-p(USFS)	1992-2000	
61420102 Miller Cr nr Beaver Marsh	supportive-p(USFS)	1993-2000	
61420103 Sand Cr nr Lenz	supportive-p(USFS)	1992-2002	
61420104 Sink Creek nr Lenz	supportive-p(USFS)	1995-2000	
14060800 Big Marsh Cr ab Collins Ranch nr Crescent	supportive	1924-29/sparse	
14061000 Big Marsh Cr at Hoey Ranch nr Crescent	supportive-c ………………	1912-14,24,(24-28),28-59	1912-2000
14145500 M. Fk Willamette R ab Salt Cr nr Oakridge	supportive	1935-1962	
14147500 N. Fk of M. Fk Wilamette R nr Oakridge	supportive	1909-16,35-95	
14308000 South Umpqua R nr Tiller	supportive/basis	1911-12,40-2002	
14327500 Rogue R ab Bybee Creek	primary, supportive	1930-52	1930-2000
14328000 Rogue River ab Prospect	primary/basis	1908-12,24-99	1914-2002
14330000 Rogue River bw Prospect	primary	1914-2002	
14330500 S. Fk Rogue ab Imnaha Cr nr Prospect	primary	1931-50	
------------ S. Fk Rogue + S. Fk Power Cnl nr Prospect	supportive	1924-84	1924-2000
14331000 Imnaha Cr nr Prospect	primary, supportive	1934-49	1934-2000
14333000 M. Fk Rogue R nr Prospect	primary	1925-55	1925-2000
14333500 Red Blanket Cr nr Prospect	primary, supportive	1925-82	1925-2000

Notes: -p = provisionsal (source), -c = combined, /basis = basis station

Spatial data: Maps and historical documents used and developed in this study –

Pre-development field conditions were documented using late 19th and early 20th century maps published by the United States Geological Survey and United States Reclamation Service. Mapped GIS coverage documenting the locations and areas of irrigated lands was obtained electronically from the State of Oregon. Maps, reports, and articles documenting pre-development (i.e., frontier) field conditions were reviewed, as published by the following listed sources:

United States Geological Survey -

1:250 000 scale sheets mapped by plane-table methods, late 1880s
Ashland
Klamath
Modoc
(pre-development conditions)

Twenty-first Annual Report of the United States Geological Survey to the Secretary of the Interior, 1899 – 1900. Part V, Forest Reserves, Cascade Range and Ashland Forest Reserves, Oregon. John B. Leiberg. Washington, District of Columbia. p. 209, ff., inclusive of Plates 71 and 72. (pre-development conditions)

Nitrogen and Phosphorous Loading from Drained Wetlands Adjacent to Upper Klamath and Agency Lakes, Oregon. Water-Resources Investigations Report 97-4059, Daniel T. Snyder and Jennifer L. Morace, investigators. U.S. Geological Survey, Portland. 1997. (pre-development to development conditions)

Unites States Reclamation Service -

1:250 000 scale compilation sheet of late 1880s mapping completed by the USGS and published by USGS and USRS in 1905 as Klamath Project, California – Oregon, General Progress Map, April, 1905. (pre-development conditions)

1:48 000 scale sheet (left-half) published by US Reclamation Service in 1905 as Topographic and Irrigation Map, Upper and Lower Klamath Projects, California – Oregon, 1905. (pre-development conditions)

Klamath Project, California – Oregon, General Report, September, 1910. E. G. Hopson, Supervising Engineer; W. W. Patch, Project Engineer. United States Reclamation Service, Klamath Falls. (pre-development to development conditions)

United States Bureau of Reclamation -

Comprehensive Report on the Development of Water and Related Resources of the Upper Klamath Basin, March, 1954. E. L. Stephens, Project Manager. (Also known as the Upper Klamath River Basin [Report], Oregon – California.) (pre-development to present-day conditions)

State of Oregon -

Report of the Oregon Klamath River Commission, December, 1954. Lewis A. Stanley, Engineer. (pre-development to present-day conditions)

Klamath River Inter-Tribal Fish and Water Commission, and Humbolt State University, Arcata -

Relationship between flows in the Klamath River and Lower Klamath Lake prior to 1910. Bertie J. Weddell. Proceedings, Klamath Basin Fish and Water Management Symposium (February, 2002), Part 1: Geology, Hydrology and Water Quality in the Klamath Basin, pp. 1-43 to 1-55. (pre-development to development conditions)

Oregon State University -

Water Allocation in the Klamath Project, 2001: An Assessment of Natural Resource, Social, Economic, and Institutional Issues with a Focus on the Upper Klamath Basin. Oregon State University Special Report 1037, reprinted May, 2003, 401 pp. (pre-development to present-day conditions)

Part 2: Assessment of pre-development hydrologic conditions

<u>A retrospective view of the Upper Klamath Basin: Changes from pre-development conditions</u> –

The present-day watershed tributary to Upper Klamath Lake has been fundamentally changed from that existing under pre-development conditions. Among the most extensive changes has been the development of irrigation and grazing, particularly on the floor of the Wood River Valley. Ubiquitous changes include the presence of roadways, channelization of streamcourses, clearing of land for grazing, clear-cutting for logging, and the diking and drainage of marshlands around the perimeter of Upper Klamath Lake. Many of these changes from the natural condition of the pre-development landscape may have produced an impact that is difficult to quantify. Other changes were significant.

Wood River Valley –

Within the area of the Klamath River watershed that is tributary to Upper Klamath Lake there have been considerable changes that have altered the appearance of the landscape and changed the character of the watershed. Before development, the Wood River Valley most likely appeared as a grassland prairie with ground-water seeps and wetlands scattered along the valley floor. A woodland crossed the northern end of the valley floor. Streams flowing eastward from the Cascades, and southward from the flank of Mount Mazama, as well as from springs along the eastern valley wall, had attendant riparian marshes that supported sedges and rushes. These riparian areas probably had within them stands of Birch, Alder, Willow (*Populus* sp, *Salix* sp), Ash, Dogwood, and Elderberry, all of which are water loving trees or shrubs. Today, the Wood River Valley has been extensively reclaimed for pasture. The riparian marshes and stands of trees are mostly gone except for those noted presently along the margin of the valley floor such as along Crooked Creek and Fort Creek, and in the vicinity of Wood River Springs. Streams flowing into the valley have been extensively re-channeled and diverted for flood irrigation of pasture. A network of drains collects end-field losses and ground water from irrigation applications and percolation losses. This drain water is successively distributed into ditches and laterals to again be used to irrigate additional pasture. Percolation losses from flood irrigation also recharge the basin-fill ground-water reservoir of the Wood River Valley and cause increased ground-water underflow into Upper Klamath Lake.

In the Wood River Valley, numerous wells penetrating the basin-fill produce artesian ground water from a regional basalt aquifer that is under confined conditions. Such water is used for irrigation, some stock watering, and other uses. Many of these artesian wells are uncapped and may be observed to be freely flowing. The consequence of these wells on ground-water discharge to Upper Klamath Lake from the regional aquifer is difficult to assess and was not determined.

Sprague and Williamson Rivers –

Riparian systems similar to those evident for the pre-development condition of the Wood River Valley were likely present also along the streamcourses of the Sprague and Williamson Rivers. Development of irrigated land and other similar changes like those in the Wood River Valley may be noted along the streamcourse of the Sprague River. Much of the marshland and valley-bottom wetland in the upper Sprague, in the vicinity of the towns of Beatty and Sprague River, has been reclaimed and is irrigated. The primary crops include alfalfa and hay grass. Water is diverted from the Sprague just above its confluence with the

Williamson River for irrigation of land on the Williamson delta adjacent to Upper Klamath Lake. However, along the streamcourse of the Williamson River, to which the Sprague is a tributary, there are few changes in the stream reach below Klamath Marsh. Although some of the wetlands of Klamath Marsh have been drained and reclaimed, much of the irrigation in the upper Williamson takes place above Klamath Marsh. Alfalfa and hay grass are the primary crops.

Within the Sprague and Williamson watersheds, and especially that of the Sprague, numerous wells pump from the confined regional aquifer. Assessment of the effect of this pumping on streamflow and inflow to Upper Klamath Lake was not assessed.

Other changes in the Upper Klamath watershed -

Other changes in the watershed include clear-cutting for timber harvest, land clearing for pasture and ranching, suppression of fire in forested areas, and the consequent invasion of juniper which forms stands in clearings and in areas adjacent to forest land that were not previously known to have juniper. Extirpation of beaver, channelization and diking of streamcourses for flood control and land reclamation, and roadway encroachments, have consequently reduced detention of streamflow and changed the character of stream baseflow from that incurred under natural conditions. These aspects are very difficult to assess on a month-to-month basis. Well-managed forest clear-cutting may have little overall hydrologic impact. Invasion of juniper may offset increased runoff from agricultural clearings. The hydrologic consequences from changes such as clear-cutting, land clearing, and juniper encroachment, may offset one another to produce little end result or noticeable effect. The changes from extirpation of beaver are readily seen in channel entrenchment and the loss of woody debris within or adjacent to stream channels, loss of extended stream baseflow, loss of flow detention in higher flow events, and the elimination of detention losses to evaporation, bank storage, and to attendant marshes that were caused by beaver ponds. Fire suppression may also be responsible for some of these effects.

Changes to Upper Klamath Lake –

Although certain aspects of Upper Klamath Lake appear today much as they did prior to the 20th century, the lake has changed considerably from that existing under natural conditions. Information about the natural condition of Upper Klamath Lake is not as readily available as that for Lower Klamath Lake. Changes in the condition of Upper Klamath Lake, however, are minimal when compared to changes due to reclamation of Lower Klamath Lake, and this may explain some of the noted difference in available documentation regarding the pre-development condition of Upper Klamath Lake. Many of the changes to Upper Klamath Lake were, nonetheless, significant. Management of the water-surface elevation of the lake by regulation of the outfall has allowed effective diking and reclamation of marshland that once was a part of the natural lake. These dikes not only prevent the lake from invading reclaimed land, they have established a new perimeter for the open-water surface of the lake and have allowed reclamation of much of the lake floor in the shallower portion of the lake. Ground-water elevations are managed for these reclaimed areas by a series of drains and pumps that discharge the drain-water into the lake. Within an overall perspective, the combined diking and reclamation of marshland, and the regulation of the outfall, has fundamentally changed the hydraulic performance of the lake. Within the perspective of this study, an evaluation of these changes and conceptual definition of the pre-development lake was necessary to understand how the lake performed as a natural water body in response to the natural inflow to the lake. To understand this performance, an understanding is necessary of changes in the watershed tributary to the lake as the natural system of the lake and watershed are inextricably linked in their consequence to the natural outfall of the lake. A general conceptual view of the Upper Klamath watershed is given in *Figure 2*. The description given with the figure caption explains the conceptual process required to estimate pre-development natural outflow from Upper Klamath Lake.

Changes to Lower Klamath Lake –

Lower Klamath Lake, as documented by a very detailed planimetric survey completed by the U.S. Reclamation Service in 1905, was already showing the progress of changes due to development that was just beginning at that time. However, in 1905 very nearly all of the pre-development aspect of the lake, and its marshlands, was still in place. Some environmental and hydrologic aspects of the natural lake may be surmised from somewhat scant yet apparently well-documented field evidence about some of the observed conditions at the lake. Documents reviewed about Lower Klamath Lake are listed in the reference section at the end of the report.

The pre-development lake seemed vast given the sense of the associated marshland and open water comprising the lake. Generally, the natural Lower Klamath Lake was a very shallow water body that averaged less than about 5 or 6 feet in depth. Inflow to the lake was from backwater overflow of the Klamath River and through the bulrush wetland marsh adjacent to the river, and through the naturally deep channel of the Klamath Strait. Backwater control of this inflow was by the Keno reef at an elevation of about 4083 ft (USRS elevation datum). The broad, wetland marsh surrounding the central, open-water area of the lake, was growing in very shallow water that had little depth near the lakeshore. Two to three miles from the lakeshore, water was about 4 to 6 feet deep. In deeper water and around the perimeter of the open-water area, floating bulrush mats formed islands of various sizes generally not larger than a few acres. Although the vast, even though shallow-water areas of contiguous bulrush marsh did not invade deeper water, the marsh apparently bridged some narrower sections of open water thereby giving this extensive marshland a reach from the southeastern to the northeastern shore of the lake. The greatest expanse of open water was resident in the deeper, southern portion of the lake where evaporation made the lake moderately alkaline. This increased alkalinity was probably a factor limiting the growth of bulrush within that part of the lake. Alkalinity was apparently so high within White Lake, at the eastern limit of the northeastern shore, that no bulrush could invade. Further, nearing the end of the summer, warm water may have been resident especially within the more alkaline, southern part of the lake that held the deepest open water. As evaporation and marshland transpiration lowered the water surface of Lower Klamath Lake during the summer, the presence of this warm water may have been enhanced somewhat by the late-summer influx of warm water issuing from Upper Klamath Lake. During the most typical years, the stable water-surface elevation for the lake was probably about 4084 to 4085 feet, more or less.

Evidence suggests that the flood of 1888 was of such magnitude that the water-surface elevation of Lower Klamath Lake may have exceeded 4088 feet for a considerable time. Under these conditions, much of the lake would have appeared as open water. Wetlands attendant to the lake, especially within the central portion of the water body, would have been submerged and would not have easily thrived. The early spring influx of cold water to the lake may have fragmented much of the nearly floating mat of dormant bulrush at the edge of deeper water. Hence, there may have been times when the open-water area of the lake was considerably more expansive and dominant than seen typically. Further, just at the outlet of Lake Ewauna at the northern end of the lake, high-water overflow of storage through the Lost River Slough would have been considerable, perhaps exceeding 800 to 1000 cfs during such floods.

Evidence also suggests that during drought, the wetland marsh succumbed to the dry conditions and deteriorated. This may be surmised from the condition of the lake that was seen as reclamation of the lake floor progressed. Large islands of emergent growth would initially appear and, as dry conditions continued, these islands would become fragmented. Alkalinity in the lake would have increased and caused accelerated deterioration of the bulrush wetlands. Within the hot, dry, late summer months of such times, vast expanses of the wetland were senescent and fetid. Open-water areas were somewhat shallower, and during such dry conditions, would have been warmer and more brackish. The water-surface elevation of the lake during such dry years may have been about 4083 feet, more or less, during much of the summer.

Miller Lake, adjacent to Lower Klamath Lake on its western shore, probably received water by overflow from Lower Klamath Lake during high-water years. During most of the time, however, Miller Lake was separated from Lower Klamath Lake by a narrow berm that defined the eastern margin of the open-water surface of Miller Lake. As such, Miller Lake may be seen as being in hydraulic connection with, and receiving water from, Lower Klamath Lake by ground-water underflow. Hence, Miller Lake was a part of Lower Klamath Lake. Due to extreme evaporation, the water within Miller Lake was highly alkaline and, consequently, the water-surface elevation in Miller Lake would always have been somewhat lower than in Lower Klamath Lake. The difference in elevation between the water surface of Lower Klamath Lake and that of Miller Lake would have provided the driving force for the ground-water underflow.

In 1905, the reclamation of Lower Klamath Lake began for recovery of the land to agricultural uses. Completion in the summer of 1908 of a railroad dike east of the Klamath River cut off all flow into Lower Klamath Lake except flow through the Klamath Strait. By 1917, with closure of the Klamath Strait, the ending phase was initiated in draining the vast area of open water and marshland of Lower Klamath Lake. Within a decade, the natural character of Lower Klamath Lake was gone. Over the intervening time to the mid-1950s, the dry lakebed of Lower Klamath Lake was extensively reclaimed for irrigated agriculture and this reclaimed area is part of the Klamath Project operated by the U.S. Bureau of Reclamation. However, as the lake had at one time been one of the most diverse ecosystems in North America, being along the Pacific flyway, a designated portion of the drained lakebed was set aside and allowed again to be filled, which is now the Lower Klamath National Wildlife Refuge.

Determination of the undepleted natural flow of the Klamath River at Keno requires a conceptualization and simulation of Lower Klamath Lake in much the same manner as that for Upper Klamath Lake. The simulation must consider the natural inflow to the lake, storage and the evapotranspiration loss of water within the lake, and the resulting outfall at the lake outlet. Such a simulation must also account for losses of storage through the Lost River Slough at the northern end of the lake.

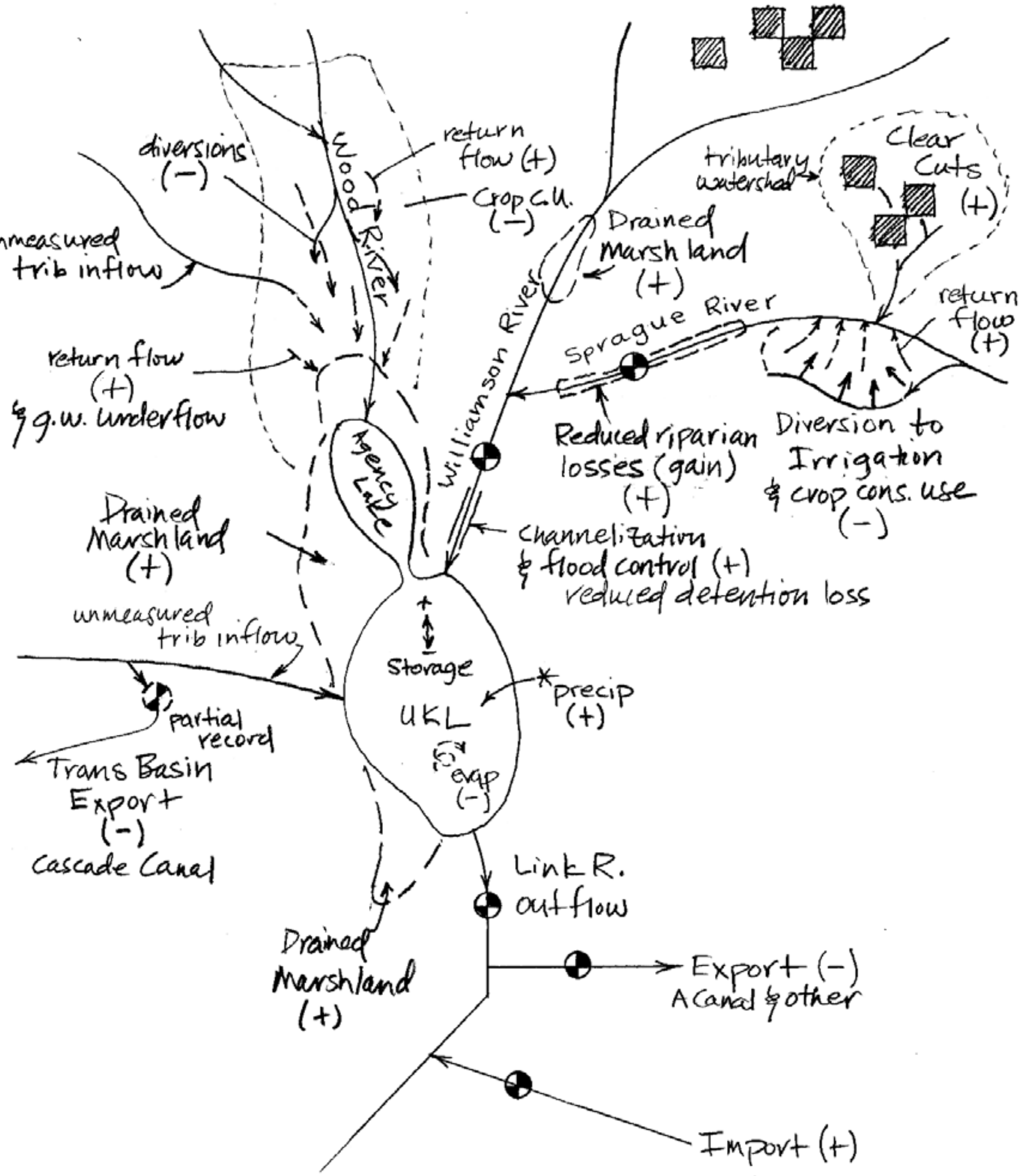

Figure 2. Cartoon of present-day watershed of Upper Klamath Lake. For a generalized view of the water budget shown in this conceptual view, changes in streamflow due to current conditions are indicated by (+) for gains in flow or (-) for losses in flow. As a general rule for the water budget, + and – factors in the watershed above the lake must be reversed to determine undepleted natural inflow to the lake, and must consider unaccounted natural losses that were reclaimed by development. Assessment of Upper Klamath Lake as a natural water body and determination of undepleted natural flow at Link River requires simulation of the lake based upon the determined natural inflow tributary to the lake for a chosen period of record, and the dynamic changes in lake storage, lake wetland marsh evapotranspiration, and water surface evaporation that would have occurred under natural, pre-development conditions.

Natural streamflow determination: Evaluation of the Williamson River watershed –

Watersheds of the Sprague and Williamson Rivers, which comprise the total of the Williamson River watershed, capture and provide the greatest part of the natural inflow to Upper Klamath Lake. Restoring to natural flow the gaged flow of the Sprague and Williamson Rivers required, therefore, an assessment of lands irrigated by diversions of streamflow, and of reclaimed natural marshlands. Net consumptive uses incurred by diversions to irrigated lands have depleted streamflow and such depletions must be added back to gaged flow. Consumptive uses that would have been incurred by reclaimed natural marshlands would have caused a loss in natural flow, and must be subtracted from the derived result. The water budget for natural flow at the gage is straightforward:

natural flow = gaged flow + crop net consumptive use – reclaimed natural marshland net evapotranspiration

Of usual consequence to this type of water budget would be irrigation return flows that are delayed in returning to the stream. Because the Sprague and Williamson Rivers do not have well developed and transmissive valley fill alluvial aquifers, and because most of the irrigation diversions from these streams irrigate land that is in proximity to the stream, irrigation return flows may be considered due to field runoff from flood irrigation and not drainage to the stream of irrigation percolation losses that recharge a ground-water reservoir hydraulically connected to the stream. As such, these return flows are not delayed significantly in returning to the stream after the application of diverted water to the irrigated field. This water, therefore, is already reasonably accounted at the gage and would have been considered a factor in diversion from the stream and irrigation of crops if otherwise delayed by ground-water drainage to the stream. Therefore, the net impact to the gage is from the net consumptive use incurred by the crops being irrigated as this is the amount of water lost and not appearing at the gage.

Crop net consumptive use may be defined as potential crop evapotranspiration less effective precipitation. For marshland, this same definition applies. Marshland net evapotranspiration is simply the potential evapotranspiration that may occur from the marsh less effective precipitation. Because not all precipitation is sufficient to offset potential evapotranspiration, only the part that is effective in doing so is considered. These uses by crops and marshes were calculated using a modified SCS Blaney-Criddle model. Meteorological data from nearby weather stations were used in supporting the calculations, and included monthly precipitation and monthly average temperature for the period 1947 through 2002. Although many meteorological records were fairly complete, nearly every record required reconstruction or estimation of missing values to gain a complete time series for the selected period of analysis.

Assessment of irrigated lands was based on information provided by the State of Oregon Water Resources Department. Affected natural marshland areas were assessed through photo-interpretation of ortho-rectified color aerial photography provided to the Klamath Area Office by the Fish and Wildlife Service. Detailed evaluation of these areas was posted on 1:63 360 scale 15 minute quadrangles which were overlayed for each coverage type to determine the affected natural marshland area for the natural loss assessment. Affected and non-affected marshlands were also mapped based on indications shown on the 15 minute quadrangles. The areas of affected marshlands were planimetered, as these were the reclaimed marshland areas, and the total of these areas noted for each individual quadrangle where marshland coverage had been mapped.

Watershed conditions were also evaluated using a mosaic-composite of individual 15 minute digital ortho-photo quads reproduced at a scale of 1:63 360. Four individual yet adjacent 7.5 minute ortho-photo quad frames were used in developing each these 15 minute ortho-photo quads. The individual frame images are available from the USGS, and spanned two image acquisition dates. The composite ortho-photo image for each 15 minute quadrangle at its respective imaging date was examined for evident changes in watershed conditions. From the first image in 1994 to the last in 2000, generally noticed changes in watershed conditions were related to re-growth of logged areas. Most clear-cutting was noted as non-extensive and appearing as randomized, smaller cut areas, which would indicate this activity has had minimal impact to hydrologic response of the watershed. These examinations were completed primarily for the Sprague River watershed.

The present-day discharges of both the Sprague and Williamson Rivers are measured by gaging stations having complete records beginning well before the period of interest. These gages are in the vicinity of the confluence these two major streams, near the town of Chiloquin. Given the completeness in these gaging records, an assessment of watershed areas or an evaluation of discharges for individual subwatersheds was not critical to estimation of the natural flows. The evaluation, therefore, was limited to completing an assessment of factors that would have significantly altered natural streamflow at the selected gages near Chiloquin.

The Sprague River –

The most significant changes affecting natural flow of the Sprague relate to the development of irrigated croplands and the reclamation of marshlands for irrigation. Evaluation of net consumptive uses for irrigated lands and for reclaimed natural marshlands was based on meteorological data collected at several sites. Incomplete records for the Round Grove station, and for the Sprague River station were restored by correlation with other nearby stations. For the Sprague above Beatty, consumptive uses were determined for irrigated pastureland and marshlands based on meteorological data for the Round Grove station. Below Beatty, consumptive uses were determined similarly using meteorological data for the Sprague River station. The total of these net consumptive uses for irrigated pastureland was added to the flow record for the Sprague River near Chiloquin. Similarly, because reclaimed natural marshland would have depleted the flow of the Sprague under natural conditions, the loss determined by the net consumptive use of the reclaimed marsh in each respective area was subtracted, in total, from the resulting flows determined for the Sprague River gage.

The Williamson River –

The evaluation of the Williamson River required consideration of several factors that are consequential to present-day gaged flows. The irrigated area of interest for the Williamson is for pastureland that lies in the upper part of the watershed above Klamath Marsh. Field surveys indicate that pastureland development in this area has not effected significant changes to the marshland character associated with the stream. However, below this irrigated pastureland the natural extent of Klamath Marsh has changed as the perimeter of the marsh, especially within its lower segment, is apparently somewhat different under current conditions than noted for pre-development conditions. In addition, diversion of flow into the Modoc Canal from the Sprague below the Sprague River gage near Chiloquin depletes the inflow of the Sprague to the Williamson. Because the principal gage for the Williamson lies below the confluence with the Sprague, these diversions by the Modoc are a depletion to the gaged flow of the Williamson. Therefore, the estimated diversion requirement of the Modoc was added to the gaged flow of the Williamson, and the current gaged flow of the Sprague subtracted to restore the present-day flow of the Williamson to a pseudo-gage, or node, above its confluence with the Sprague. Within the reach of Williamson from below Klamath Marsh to the confluence with the Sprague, there has been little apparent change to the natural character of the stream.

The evaluation of irrigated pastureland depletions and losses from Klamath Marsh in the upper Williamson was based on restored meteorological data given for the Chemult station, which is in the vicinity of these features and at an elevation similar to these areas. Although a limited irrigated area in the upper Williamson is closer to the lower-elevation station at Sprague River than the Chemult station, data for Chemult were seen as generally more representative in this case due to the consistency of weather patterns and elevation with that of the area being considered.

The difference between pre-development and present-day areas for Klamath Marsh has determined the net change in marshland area that has affected part of the natural flow of the Williamson. The present-day area of Klamath Marsh was provided by OWRD. Pre-development area of the marsh was determined from a 30 minute extract of the Chiloquin sheet taken from the 1906 compilation map published by the USRS. The 1906 map, as mentioned elsewhere in this report, was published as a 1:250 000 scale compilation of several adjoining 60 minute sheets mapped by the USGS in the mid 1880s using plane-table methods. A portion of the pre-development marsh was also determined from the 1935 Chemult 1:125 000 scale 30 minute quadrangle that is published by the USGS. Although field mapping of this quadrangle was also completed using plane-table methods, the accuracy and quality of the land-surface representation is superior to that shown for the adjoining area on the 1906 compilation sheet. Pre-development marshland areas were posted on 1:62 500 scale 15 minute quadrangles of Klamath Marsh and Lenz, that had been scale-reduced to 1:125 000. These present-day 15 minute quadrangles were published by the USGS in 1957. The lower segment of the marsh that is generally west and south of Wildhorse Ridge was interpretively delineated. The upper segment of the marsh in the area generally north of Wildhorse Ridge, was delineated as the marshland area appearing on the scale reduced Klamath Marsh quadrangle, and as posted directly from the marshland area indicated on the 1935 Chemult sheet. The appearance of this upper segment shows apparently little change from its presumed pre-development area. However, registration of land surface features and of the marshland areas on the more recent sheets with those on the earlier USRS sheet shows the existence of mapping errors on the older sheet that are difficult to reconcile. Some of the marshland indicated on the USRS sheet was not included for this reason. The evident impression of the landscape, however, is interpretively assessable from the older USRS sheet and the appearance of the marshland shown on the present-day USGS sheets was deemed representative of these earlier mapped conditions.

Evaluation of depletions to the Williamson by diversions of the Modoc Canal was completed by using restored meteorological data for Chiloquin. This depletion is to the Williamson gage near Chiloquin and is attributable solely to the diversion taken by the Modoc from the

Sprague River for use on irrigated lands below the gage. Therefore, the gage for the Williamson was restored to its present-day flow above the Sprague without the affect of this depletion. This was accomplished by adding the estimated diversions for the Modoc back to the gaged flow history for the Williamson near Chiloquin, and subtracting the present-day gaged inflow from the Sprague. This restored present-day flow for the Williamson above the Sprague was used for determination of natural flow for the Williamson. To determine the undepleted natural flow at this location, the total net consumptive use for irrigated pastureland in the upper Williamson was added to this flow record. Similarly, because reclaimed natural marshland would have affected the flow of the Williamson under natural conditions, the loss determined by the net consumptive use of the reclaimed marsh area was subtracted from the resulting flow that had been determined for the Williamson.

Natural streamflow determination: The northern and western Wood River Valley –

Inflow to Upper Klamath Lake was quantified by developing synthetic natural time series for all contributing areas in the Wood River Valley. Specifically, the northern and western tributary streams are discussed herein. A standard methodology was developed and followed to quantify each tributary's inflow between October 1947 and September 2001. The process used is described below and the application to each specific watershed is outlined in detail in Appendix 1-4X.

Not all watersheds in the Klamath and Rogue River basin have the same basin characteristics. Varying geology and dominant flow regimes warranted the necessity of several basin specific approaches. Synthetic flow histories for drainages like Fourmile Creek, Annie Creek, and Sun Creek, were generated using special methods adapted specifically for each of these streams. Methods used in development of the synthetic time series are described in detail in Appendix 1-4X.

Standard Streamflow Quantification Methodology –

Even though the floor of the Wood River valley has been altered significantly within the last 100 years, most of the contributing headwaters remain in a relatively natural condition. The first two logical steps for quantifying streamflow in relatively ungaged rivers are:

1. Obtain all available gaged data, including any miscellaneous, instantaneous streamflow measurements, and
2. Determine how natural these data are.

Several years of gaged streamflow information is available for Upper Klamath Lake and Wood River tributaries, and the majority of that data can be considered natural or "unregulated." In order to determine how natural the available data are, the presence of any upstream diversions into or out of the stream should be determined and quantified, as well as effects of any major land characteristic changes such as those resulting from timber harvesting and fire suppression. The measurement or gage location should be investigated to ensure the majority of water captured or produced by the watershed is measurable at the surface. Several tributary gages were located on alluvial fans or on an alluvial valley bottom where a significant amount of water that is produced by the watershed and contributes as inflow into Upper Klamath Lake may be in the subsurface at that particular location. Where deviations from the natural condition were evident, adaptations to this process were made to naturalize the gaged-streamflow data based on site-specific needs before continuing with the standard process.

Streamflow measurements used in this investigation are available from the United States Geological Survey (USGS), the United States Department of Agriculture - Forest Service (USFS), and Oregon Water Resources Department (OWRD). Most USGS data are readily available in CD-form from Hydrosphere, but miscellaneous and peak streamflow measurements are mainly found in the Water Resources Data Publications for Oregon, including summary and individual water year volumes. The USFS has made several years of daily gaged record available on the OWRD website. Additionally, more recent years of daily gaged data and numerous miscellaneous streamflow measurements were obtained by contacting the Winema National Forest – Supervisor's Office in Klamath Falls, OR. Miscellaneous streamflow measurements were obtained electronically from OWRD.

Temperature and precipitation data were not used in the standard process, however these data were integral in estimation techniques employed for unique watersheds, such as Annie Creek and Denny Creek. Such data are available from the Oregon Climate Service or the National Oceanic and Atmospheric Administration. Incomplete data records were extended using the same techniques employed for streamflow record extension, as described by Reid, Carroon, and Pyper (1968) for the state of Utah. Watersheds were delineated using a Geographic Information System (GIS) and electronic topographic maps (Digital Raster Graphics) available on the USGS EarthExplorer website. Other GIS information was collected from the USFS and the state of Oregon, which provided several basic GIS information layers.

As stated before, the process to determine a synthetic time series for most tributaries was generally identical. The subsequent steps in the standard process are:

3. Determine similarities between Wood River valley tributaries and gaged streams nearby based on geology, hydrograph shape or prominent flow regime, and baseflow characteristics.
4. Develop total monthly flows for gaged periods by relating instantaneous flow measurements to at least 2 other concurrent daily gaged records.
5. Relate monthly total discharges to those from nearby, similar gage with large period of record.
6. Create a synthetic natural time series based on monthly total flow correlation equations.

In determining the similarity to other watersheds, several basin characteristics were compared. The geology, variation in areal precipitation, climate, aspect, and dominant flow factors of each basin were characterized to find similar gaged and ungaged watersheds. The separation between watersheds also determines the transferability between similar watersheds.

To determine the best gage transference methodology and equation, gaged streamflow information was initially transferred between all adjacent gaged watersheds using basin characteristics. Such characteristics as watershed area, weighted-average annual precipitation from 1961-1990, and effective precipitation (average annual precipitation / drainage area) were used to rescale the time series from a known gage to represent another (gaged) watershed. In all transference cases, the resultant synthetic time series could not recreate the variability exhibited by the other known gage, except in one case. The only transference that generated adequate variability used a gage in a non-adjacent watershed, from over 36 miles to the northeast. Despite being able to recreate adequate variability between gaged watersheds, an equation to accurately transfer this gage to ungaged watersheds could not be developed due to the inability to produce a sufficient least-squares best-fit line. Climatic variation evident across the distance between this gage and the Wood River Valley did not support confidence in using this equation as the synthetic time series, since derived results would not have been representative.

Most Klamath Lake basin watersheds had several years of daily gaged data, but the data available was still minimal. In order to build a larger data set, monthly total flow estimates were made using concurrent instantaneous streamflow measurements. When sufficient concurrent measurements were available between a nearby, daily record and the desired watershed, at least one measurement per month for several months, monthly total flows for the otherwise ungaged watershed was estimated by rescaling the somewhat extensive daily gaged records from nearby watersheds. This rescaling is sometimes termed hydrograph-matching and was typically done with at least 2 nearby gages, which generally produced very similar results. After creating an estimated daily gage record for the desired watershed, daily values were summed by month to create total monthly discharge estimates. Only estimates that were generated from concurrent instantaneous flow measurements observed before, during, and after that month were considered to be accurate and were used in further correlation analyses.

Since an accurate basin-characteristics-based equation could not be determined, a variety of linear and curvilinear correlations were used to develop each synthetic time series. Numerical correlation methods are considered to provide more accurate baseflow characteristics and streamflow variability for the Wood River Valley than any of the watershed characteristics techniques considered. For most watersheds in the valley, the several years of gaged information represents natural conditions, since land management activities have not affected the streamflow hydrograph (USDA, 1994; USDA, 1995; USDA 1996). A correlation between these data and another gage with a more extensive period of record was the common procedure used. Monthly total discharge values from a nearby, similar gage record were correlated to those from each desired watershed. Correlations were developed for specific flow regimes (low-flow or high-flow) within individual months, each season, or for all months, depending on the number of available concurrent values. The least-squares method defined by Pollard (1977) was used to determine the accepted best-fit line. However, as correlation declines, the least-squares line does not always capture sufficient variability. This poses a critical problem. As a remedy, the line of minimum absolute deviation (MAD) was used to capture variability. The explained variability captured by a line is determined by calculating r^2 (Lapin, 1983) as modified for the line of minimum absolute deviation or a generally similar fitted line (see Zebrowski, 1979; Troutman and Williams, 1987; Williams 1983). The use of these modified lines ensured sufficient variability was recovered even though as correlation declines, the variability recovered is unexplained. As such, the unexplained variability that is recovered is an artifact of the correlation process. These methods are consistent, however, with those used by Reid, Carroon, and, Pyper (1968). Actual gaged monthly total flows were considered more accurate and were depended on more heavily than monthly estimates. Correlation equations were used to develop synthetic time series from October 1947 to September 2001.

Watersheds evaluated –

The following Wood River tributaries were quantified using the standard process described above:

Stream Name:	Natural Tributary to:
Sevenmile Creek	Upper Klamath Lake
Threemile Creek	Crane Creek
Nannie Creek	Cherry Creek
Cherry Creek	Fourmile Creek
Rock Creek	Crystal Creek
Moss Creek	Upper Klamath Lake

The time series for each watershed was developed uniquely and is explained in more detail in Appendix 1-4X. Any deviations from the standard process are described in this appendix, along with a qualitative discussion of each synthetic time series. Flow histories for other UKL tributary streams not listed above are also described in this appendix.

Natural streamflow determination: The central and eastern Wood River Valley –

Three primary streams in the central and eastern Wood River Valley, the Wood River and its tributary Fort Creek, and Crooked Creek, provide natural inflow to Upper Klamath Lake. Developing a representative estimate of this inflow requires consideration of three primary and inclusive elements. The first element, which was completed as described above, required the determination of the inflow to the Wood River from Annie Creek and Sun Creek, the sum of which form the headwaters of Wood River. Second, the ground-water accrual to the Wood River and Crooked Creek must be determined. For the Wood River, ground water is derived from Wood River Springs, also a tributary at the head of Wood River on the valley floor, and from ground-water fed Fort Creek, a tributary to the Wood River that heads on the margin of the valley floor to the east of Fort Klamath. Crooked Creek presents similarities to Fort Creek as the flow in Crooked Creek is derived from many springs and seeps along the eastern margin of Wood River Valley. These springs are found from southeast of Fort Klamath, near the Klamath State Fish Hatchery, and southward to the Klamath Agency. Third, a riparian marsh system was attendant to each of these streams and caused incurred losses to flow of these streams. Such marshlands, therefore, required assessment to determine the magnitude of these losses.

Wood River –

Evaluation of the Wood River included a comprehensive survey of published miscellaneous flow measurements that were made by the USGS from approximately 1900 to generally about 1970. Although some later measurements were used, records prior to the early 1970s present the best opportunity to capture measured flows that are unaffected by accelerated cultural development. Flow measurements considered included those made at Fort Klamath, and elsewhere above this location, generally during the winter season. Some aspects of the flow were developed from an analysis of the gaged record at Fort Klamath from 1914 to 1936. This flow record contained several missing years and the gage was discontinued in 1936. These measurements were compiled, sorted by month of occurrence, and evaluated.

Measurements that had been affected by diversions and other upstream uses were culled from consideration. Based upon measurements that were considered, a representative, monthly-basis estimate was developed of natural spring fed inflow and ground-water accrual that is tributary to the Wood River above its confluence with Fort Creek. The indicated average natural flow of Wood River Springs was about 293 cfs. From the springs to the gage at Fort Klamath, there is sparse information that the estimated additional accrual averaged about 56 cfs. However, there is reason to suspect this accrual was not by natural ground-water inflow, but by irrigation return flows that were draining into the stream.

The evaluation of Fort Creek was similarly undertaken to that of the Wood River. Miscellaneous flow measurements for Fort Creek, however, were somewhat more comprehensive than those considered for the Wood River. These measurements were compiled, sorted by month of occurrence, and representative measurements unaffected by diversions and other upstream uses were considered in developing an assessment of natural ground-water conditions for Fort Creek. The derived estimate of spring fed and ground-water inflow that is tributary to Fort Creek, and hence, to the Wood River, indicated the natural spring-flow of Fort Creek was about 89 cfs. In each case, whether for the Wood River, or for Fort Creek, the indicated locations for the gage records, and each of the miscellaneous measurements, was map-posted, or checked.

Evaluation of the stream-associated riparian system was based on a detailed photo-interpretive assessment of color-infrared ortho-photography that had been flown in July, 2002, and assembled by the Bureau of Reclamation (12-208-1000). This imagery covered approximately the eastern third of the Wood River Valley. From this imagery, and 9 inch by 9 inch prints of the acquired color infrared photography (BR-KLA-14), the trace of the previously existing, stream-associated, natural riparian area was delineated. Because the color infrared photography was provided as approximately 1:31 000 scale prints, and as an ortho-photo image mosaic scaled at 1:40 000 and at 1:10 000, these delineated areas were collectively posted on 7.5 minute quadrangle overlays that had been scale reduced to 1:40 000. These overlays were then reduced to 1:63 360 and planimtered to determine the land-surface area of the riparian marshland affecting natural flow of the Wood River and Crooked Creek. The assessed areas of these riparian marshland areas were of those exclusive to the lake wetland marsh attendant to Upper Klamath Lake.

The monthly average flows indicated for ground-water accrual to Wood River, inclusive of Fort Creek, were added to the estimated natural inflow from Annie Creek and Sun Creek, to provide the total estimated inflow to the Wood River system. Losses determined for the associated riparian areas were subtracted from this inflow, thereby providing an estimate of inflow to Upper Klamath Lake from the Wood River. For the period of interest, 1949 to 2000, this inflow was estimated to average about 420 cfs.

Crooked Creek –

The evaluation of Crooked Creek followed the same general approach taken for the Wood River. Crooked Creek is indicated to be a tributary of the Wood River, yet there is evidence this was not always so. Although the Wood River has a well-established channel along the eastern margin of the wetland marsh at the northern end of Agency Lake, an extension of Upper Klamath Lake, there apparently were times when the Wood River was lost in the wetland area, and Crooked Creek was not directly tributary to the Wood River. For pre-development conditions considered herein, Crooked Creek may have entered the Wood River along the eastern margin of the wetland marsh area just above the mouth of the Wood River at Agency Lake. The present-day channel of Wood River has been channelized and straightened generally along the pre-existing alignment the stream had under natural conditions.

Above its confluence with the Wood River, Crooked Creek flows in a tightly meandering channel along the eastern margin of the valley floor. Because there is virtually no contributing watershed area, flow in Crooked Creek is limited to inflow from several springs and ground-water seepage that arises along east bounding wall of the Wood River Valley. The accumulation of this flow is initiated about 1.7 miles southeast of Fort Klamath. These springs increasingly add to the flow of Crooked Creek. Records indicate various names for some of these springs, of which one or two were given inconsistent reference. However, for most miscellaneous flow measurements that are published for Crooked Creek, the indicated locations were sufficiently distinct that a representative assessment could be accomplished and the locations of named springs determined along the stream.

Miscellaneous flow measurements were only considered for those made during the period from 1900 to 1960 to eliminate, or restrict, the effect from development. Although diversions occur from Crooked Creek, notes in many of the records indicated if the measurements were made above, or below, these diversions, and very occasionally noted the quantity then being diverted. The inclusive body of these measurements was compiled, sorted by month, and assessed for trends due to development. Hence, a water-budget could be established based on measured spring flow and ground-water seepage that accrued to the stream. Results of the analysis indicate that a representative estimate for the undepleted ground-water influx into Crooked Creek was about 95 cfs, but may have been as high as 103 cfs.

Crooked Creek also had an associated riparian marshland like that along the Wood River. Evaluation of this riparian marsh was completed just as that for the Wood River and Fort Creek. This riparian marsh causes a loss to the flow of Crooked Creek before inflow to Upper Klamath Lake. For the period of interest, 1949 to 2000, average natural flow of Crooked Creek, inclusive of this natural loss, was indicated to be about 94 cfs.

<u>Evaluation of the natural Upper Klamath Lake</u> –

To evaluate the natural condition of Upper Klamath Lake, materials documenting the frontier condition of the landscape were reviewed. These materials, generally published under congressional authorization, or published by the U.S. Geological Survey, are documents related, respectively, to the exploration of the west by the U.S. Army, and the survey of western lands by the USGS. Earliest of these regards the report in which notes of Lt. R. S. Williamson are compiled describing the condition of the frontier that he saw in 1855. Although information by Williamson is generally of incidental interest, certain elements in the description of the landscape provide a view that has assisted in the interpretive definition to the natural lake and in visualizing the landscape. Elements derived from several diverse sources in the investigation and evaluation of predevelopment conditions have been instrumental in developing a simulation of the natural lake. These materials are listed in the references section at the end of the report.

Primary supporting information was derived from the mid- to late-1880s surveys of northern California and southern Oregon that had been completed by the USGS. These plane-table surveys were published as a series of standard 1:250 000 scale, 30 minute quadrangles and were used in other USGS publications (reports) as a base for posting field-surveyed information in describing and cataloguing the existing natural resources of the area. The most recent survey of interest (in this series) for Upper Klamath Lake was published in 1905 by the U.S. Reclamation Service as a 1:250 000 scale single-sheet compilation (USRS 6902) of several adjoining quadrangles in this 30 minute series. From a digital copy of the 1:250 000 scale compilation sheet, each of a series of 1:63 360 scale, 15 minute quadrangles were extracted and printed. These 15 minute extracted quadrangles covered the same area given by each of a series of *present-day* 15 minute planimetric quadrangles published in 1956-57 by the USGS at a scale of 1:62 500. The information contained on these 1905 extracts that related to the natural condition of Upper Klamath Lake was initially transferred, and then interpretively posted, onto scale-reduced copies of the same-area modern USGS 15 minute quadrangles, each of which was used as a base map for the compilation. These *present-day* sheets had initially been copied from originals at the published scale of 1:62 500, and then scale reduced to 1:63 360 thereby giving each sheet a conformable map scale useable for these postings. This map scale was generally chosen for all interpretive map products related to Upper Klamath Lake because the overlay of different map products, transfer of information from one map onto another, and comparison of different map series would all be at a common scale. Further, at this map scale, planimetry of delineated areas would yield one square mile for each square inch that was planimetered. Because each of the compilation maps is planimetric, the planimetered areas would be considered representative. Additional information was derived from current 1:24 000 quadrangles covering the northern end of the lake and Wood River Valley. This additional information was posted on 1:63 360 scale reduced overlays derived from the 1:24 000 quadrangles.

Factors affecting the outfall response of the natural lake –

Implementation of a simulation for the natural Upper Klamath Lake required assessment of several factors related to predevelopment conditions that were directly affecting the hydraulic response of the lake to natural inflow. These factors are as follows:

1) Estimation of the predevelopment extent of the open-water surface area of the lake.
2) Estimation of the predevelopment extent and condition of natural marshlands attendant to the lake.
3) Estimation of the storage capacity of the natural lake.
4) Evaluation of the hydraulic response of the outfall from the lake due to storage-induced changes in water-surface elevation.

Items 1 and 2, above, were extracted by planimetry of the respective areas interpretively posted on the series of 15 minute *present-day* compilation sheets. Item 3, above, was estimated based on reasonable assumptions regarding the planimetered aerial extent of the water surface of the lake at specific given elevations of the water surface above the outlet sill, or reef. The observed maximum high water surface of the lake (April, 1904) defined the estimated upper bound for the water-surface area and storage capacity of the lake. Item 4, above, was evaluated from historical information relating the monthly average elevation of the water surface of the lake, and the concurrent discharge from the lake that was recorded for monthly total flow of the Link River at Klamath Falls. The head responsive ground-water accrual to the lake is also assessed in item 4. This ground-water inflow is derived from the regional aquifer and bank storage. The assessment procedure and resulting head-response functions for determining this ground-water inflow are described in Appendix 1-6X.

With the determined areas of the natural open-water surface and natural marshlands attendant to the lake, natural losses from this water body may be estimated. As these losses directly deplete the natural inflow to the lake, the net inflow will be stored, in part, and simultaneously released, in part, as the natural outfall from the lake. For the natural lake, the following were noted or conceptually developed from materials that were researched:

Lake natural wetland marsh area………..………………………... 53,306 acres
Attendant emergent marsh area……………………………………. 9,210 acres
Open water surface area…………………………………..……….. 66,976 acres
Inundated area at maximum volumetric capacity……………….. 125,350 acres (estimated)
Maximum volumetric capacity above the sill elevation..………...768,000 ac-ft (estimated)
Lake surface elevation at maximum volumetric capacity..………. 4145.0 ft above USRS datum
Sustained average discharge at maximum volumetric capacity….…9,280 cfs or 600,000 ac-ft/mo
Outfall depth at maximum volumetric capacity…………..………….. 7.2 ft (approx)
Outfall minimum discharge noted …………………………………… 0.0 cfs (July 18, 1918)
Outfall depth at minimum noted discharge ………………………..... 1.51 ft (approx)

Integration of the natural lake –

Once the natural inflow to Upper Klamath Lake has been determined, the interrelationship of the natural factors affecting the lake as an hydrologic system may be evaluated in a simulation. Because storage within the lake inundated natural wetland marshes associated with the lake, the lake wetland marshes comprise part of the storage capacity of the lake. Because the open water surface of the lake is bounded by a natural marshland perimeter, the open water surface area of the lake is conceptually fixed and does not vary. Natural inflow to the lake is stored, in part, and released from storage at the outlet of the lake in response to elevation of the water surface of the lake. The integration of these factors is somewhat simply interrelated and accounting for them is straightforward. See appendix 1-5X.

<u>Evaluation of the natural Lower Klamath Lake</u> –

The vast expanse of Lower Klamath Lake and its marshlands presented an obstacle to seeing or understanding the nature of the lake. However, until settlement, which accelerated after the Civil War, the region still remained largely unexplored. To evaluate the natural condition of Lower Klamath Lake, materials documenting the frontier condition of the landscape were reviewed. These materials, generally published under congressional authorization, or published by the U.S. Geological Survey, are documents related, respectively, to the exploration of the west by the U.S. Army, and the survey of western lands by the USGS. Earliest of these regards the report in which notes of Lt. R. S. Williamson are compiled describing the condition of the frontier that he saw in 1855. Although information by Williamson is generally of incidental interest, certain elements in the description of the landscape provide a view that has assisted in the interpretive aspects giving definition to the natural lake, and in visualizing the landscape. Much of the information, however, was derived from several diverse sources that are listed in the reference section at the end of the report. Most are anecdotal yet have been instrumental in developing a conceptual understanding of the lake.

Primary supporting information was derived from a planimetric survey of the lake completed and published by the U.S. Reclamation Service in 1905. This very detailed survey, which was completed using plane-table methods, was published at a scale of 1:48 000. Because the survey was of the lake essentially in its natural condition, information related to marshlands and open water could be easily assessed. Important information regarding the mapped aspect of the natural lake was transferred to a mylar overlay at a scale of 1:73 184. Each significant area was defined and planimetered, including overflow areas that would have held water in storage during high-water events. Information compiled from the 1905 survey allowed definition of a detailed concept for the lake based on the planimetered areas of marshland, open water, and overflow areas that were evident. From this information, a composite curve was developed for depth of the lake versus storage.

An interconnected lake –

For Lower Klamath Lake, natural inflow to the lake is comprised solely of the natural outfall from Upper Klamath Lake and measured ground-water inflow (Quinton, 1908) from springs. The natural condition of Lower Klamath Lake, however, was a system of two lakes in addition to a complex of marshes and open water. At the outlet of Upper Klamath Lake is the elongated Lake Ewauna, which forms the head of the Klamath River. The winding channel of the Klamath River issues from Lake Ewauna, and follows a generally sinuous southwesterly course for several miles along the northwestern margin of Lower Klamath Lake before turning abruptly northwest near the lake outlet in the vicinity of Keno. Water surface elevations in Lower Klamath Lake and upstream along the channel of the Klamath River to the outlet of Lake Ewauna were controlled by a natural basalt reef in the channel at Keno. This reef held water levels in the lower lake and upstream along the channel to an elevation of about 4084 ft. A similar bedrock reef at the outlet of Lake Ewauna held upstream water surface elevations about 1 foot higher, more or less, at low flow. At higher flows, backwater in Lower Klamath Lake was stored within the lake prism and raised the water surface elevation in the complex thereby inundating Lake Ewauna, which then became a continuous part of Lower Klamath Lake. Just at the outlet of Lake Ewauna, a natural overflow channel, the Lost River Slough, as noted previously, also carried water out of the lake system when the water surface elevation exceeded 4085 feet.

Aspects affecting the natural hydrologic response of Lower Klamath Lake were controlled by inflow from the Link River, evapotranspiration from extensive marshlands associated with the lake complex, evaporation from the open water surface existing within the lake complex, and storage of water within the interconnected lake prism. Inflow from the Link River supported losses from the marshlands and evaporation from the open water surface. At the onset of the seasonal late-spring maximum in streamflow from snowmelt, and consequent maximum in outfall from Upper Klamath Lake to the Link River, losses to the resulting inflow to Lower Klamath Lake were minimal. This influx of water would be stored, in part, within the lake complex, and part of the inflow would become the outfall of the lake to the Klamath River at Keno. If this seasonal inflow were sufficiently large, the elevation of the water surface of Lower Klamath Lake would be raised upstream throughout the channel of the Klamath River above Keno, and would inundate Lake Ewauna and the entrance to the

Lost River Slough. For a water surface elevation above 4085 ft, this storage would cause overflow through the Lost River Slough and flow out of the Klamath basin and into the closed basin of the Lost River and into Tule Lake. In general, the total range in water surface elevation of the lake in response to this seasonal inflow was less than about 3 feet, more or less.

Factors affecting the outfall response of the natural lake –

Implementation of a simulation for the natural Lower Klamath Lake required assessment of several factors related to predevelopment conditions that were directly affecting the hydraulic response of the lake to natural inflow. These factors are as follows:

1) Predevelopment extent of the open-water surface area of the lake.
2) Predevelopment extent and condition of natural marshlands attendant to the lake.
3) Estimation of the storage capacity of the natural lake.
4) Evaluation of the hydraulic response of the outfall from the lake due to storage-induced changes in water- surface elevation.

Items 1 and 2, above, were extracted by planimetry of the respective areas shown on the 1905 survey. Item 3, above, was estimated based on reasonable assumptions regarding the aerial extent of the water surface of the lake at specific given elevations of the water surface. This estimate of storage capacity was based on the integrated storage within Lower Klamath Lake, overflow storage within the Lost River Slough, and storage possible in Lake Ewauna. The estimated upper bound for the water-surface area and storage capacity of the lake was determined as the elevation contour approximating 4088 ft above the USRS datum. Item 4, above, was evaluated from historical information relating the monthly average elevation of the water surface of the lake, and the concurrent discharge from the lake that was recorded for monthly total flow of the Klamath River at Keno.

With the determined areas of the natural open-water surface and natural marshlands attendant to the lake, natural losses from this water body may be estimated. As these losses directly deplete the natural inflow to the lake, the net inflow will be stored, in part, and simultaneously released, in part, as the natural outfall from the lake. For the natural lake, the following were noted or conceptually developed from the 1905 survey:

Natural marshland………………………………………………….	55,842 acres
Open water surface…………………………………………………	34,994 acres
Capacity…………………………………………………………….	332,000 ac-ft (approx)
Elevation change across capacity………………………………………	3.85 ft
Water surface elevation at maximum capacity………………………...	4088 ft (USRS datum)

Integration of the natural lake –

Once the natural inflow to Lower Klamath Lake has been determined, the interrelationship of the natural factors affecting the lake as an hydrologic system may be evaluated in a simulation. Inflow to the lake was through the bulrush marsh and Klamath Strait. The depth of the Klamath Strait was generally the same as that of the Klamath River and the floor or the channel was considerably lower than the Keno reef. Because storage within the lake inundated natural wetland marshes associated with the lake, the lake wetland marshes comprise part of the storage capacity of the lake. Because the open water surface of the lake is bounded by a natural marshland perimeter, the greatest part of the open water surface area of the lake is conceptually fixed and does not vary. The open-water area formed during higher water overflow and inundation of mud-flat and significant shore areas, however, varies with changes in elevation. Natural inflow to the lake is stored, in part, and released from storage at the outlet of the lake in response to elevation of the water surface of the lake. The integration of these factors is somewhat simply interrelated and accounting for them is straightforward. See Appendix 1-5X.

Part 3: Simulation of Upper and Lower Klamath Lakes as natural water bodies

Assumptions –

For any chosen period of record, an assessment of natural streamflow must take into account changes that have occurred in the pre-development watershed once existing above the location at which a determination of natural streamflow is desired. All of the watershed alterations that potentially effect changes in streamflow must be surveyed and examined. Some changes may have a minimal, or negligible, impact. Other changes may be accounted for, and depending on the methods used, the alterations to streamflow can be representatively determined. Many changes, however, may have an impact that is very difficult to assess, or may affect the timing and alter the volume of streamflow in such a way that the alterations noted have little overall effect except for large flows or flood events. The accounting of natural inflow and natural losses has been evaluated using accepted procedures and methods.

Natural inflow to the upper lake has been developed though a water-budget analysis of the watershed. This water budget adequately accounted for losses incurred by irrigation and reclamation of marshlands. Further, such an analysis of the Wood River Valley was obviated because losses to streamflow could be determined for the natural condition of streams in the valley. To accomplish these objectives, the following are some of the additional key *assumptions* or criteria that were necessary.

1) *The climatic regime* of the region for which streamflow records were naturalized, *must be and has been demonstrated to be consistent* across the region.
2) *The correlation analysis and statistical reconstruction of missing meteorologic and hydrologic data is therefore assumed to be adequate* and representative of the timing and variability estimated to exist for such records.
3) *Development of irrigated lands,* within the area for which gaged streamflow had been restored by using a reasonably detailed assessment of consumptive uses due to irrigation, *is assumed to have remained constant or changed little* over the period of interest.
4) *An interpretive assessment of Upper Klamath Lake* based on somewhat detailed published maps of the existing pre-twentieth century landscape, *is assumed to be adequately representative* of the pre-development condition of the lake.
5) *Difficulties encountered before 1919 with the operation of the Friez recorder on Upper Klamath Lake are assumed to be adequately understood* in the development of the rating curve used for outfall from the lake.
6) *The discharge-rating curves developed for the simulation* of Upper and Lower Klamath Lakes, *are assumed to be adequate and representative* of the hydraulically driven outfall processes for these natural water bodies.
7) *Planimetric surveys that were completed for Lower Klamath Lake* and published in 1905 by the USRS, *are assumed to be adequately representative* of Lake Ewauna, the Klamath River, Klamath Strait and pre-development condition of the lake.
8) *The conceptualization of the Lost River Slough is assumed to be adequate and representative.*
9) As the determination of relevant land areas is assumed to be representative, *the application of scientifically based theory and hydrologic method is assumed to be adequate* to the analysis of the natural flows.

With the determination of the natural inflow to Upper Klamath Lake now completed, the evaluation of the natural flow at the Link River gage, and of the Klamath River at Keno, may be realized as a simulation of a two-lake, natural system. The general objective in the simulation is to account for inflow to the lakes, losses incurred to that inflow from open-water surface evaporation and marshland evapotranspiration, storage of water remaining from this inflow, and release of water from storage as outfall from the lakes proceeds. Development of a simulation for the interaction of inflow, lake storage, and outfall, is premised on the assumption that *elements derived in conceptualizing the natural lake are representative of processes that actually occurred*.

Simulation methodology for Upper and Lower Klamath Lakes –

The basis for simulation of Upper and Lower Klamath Lakes is the *hydrologic equation* which is, simply,

inflow = outflow + change in storage .

With the given preceding information regarding lake-attendant marshlands, open-water surface area, and the relationship of storage and outfall to lake stage or gage-height elevation of the water surface, implementation of the hydrologic equation is very straightforward. A relationship for gage-height of the water surface versus storage in the lake has been developed and is readily at hand. Similarly, a discharge-rating curve has also been developed for these same data where the relationship for monthly total outfall from the lake may be computed from the determined monthly average water surface elevation. For the lake, the basic conceptual process for *sequentially accounting for these factors* in the monthly water budget is as follows:

net inflow = natural inflow – marsh net consumptive use – open water surface evaporation + precipitation to open water surface

storage = residual storage for previous month + net inflow

water surface gage elevation = gage elevation (storage)

outfall = discharge rating curve (water surface gage elevation)

residual storage for current month = storage – outfall

The sequence indicated, above, *is simply repeated incrementally on a month-to-month basis* for the selected 52 yr period of record. Computational values in the accounting are given in acre-feet per month. *Residual storage for the current month is accounted as that for the previous month as each current month is incremented to the next month* and the accounting sequence is repeated. The resulting records of interest are for natural outfall from Upper Klamath Lake to the Link River, natural outfall from Lower Klamath Lake to the Klamath River at Keno, and monthly average elevation of the water surface of each of the lakes.

<u>Upper Klamath Lake and its natural outfall to the Link River gage</u> –

The balance of the natural inflow to Upper Klamath Lake and attendant losses from the associated marshlands and the open water surface of the lake will result in the natural outfall from the lake at Link River. Inflow to the lake is therefore supporting these losses and producing this outfall. The magnitude of each factor in the water balance may be described by examination of its respective time series and giving a summary for the average year over the period of interest.

Williamson River inflow –

Natural inflow to Upper Klamath Lake from the Williamson River was determined as the sum of the restored natural flow of the Sprague above its confluence with the Williamson, and restored natural flow of the Williamson above the Sprague. Together, the combined inflow of these streams was determined as an annual average of about 910,000 ac-ft for the 52 yr period of interest being considered.

Wood River Valley inflow –

Natural inflow to Upper Klamath Lake from streams in the Wood River Valley is comprised of the total inflow from the Wood River and Crooked Creek, and streams along the west side of the valley that head on the east flank of the Cascades. For the Wood River and Crooked Creek, total natural inflow from these streams was found to average just more than 370,000 ac-ft per year for the 52 yr period of interest. Streams on the west side of the valley were determined to have a natural inflow averaging nearly 118,000 ac-ft for the 52 yr period of interest. The combined natural inflow from the Wood River Valley averages approximately 488,500 ac-ft per year for the 52 yr period of interest.

Unmeasured and estimated ground-water inflow –

Upper Klamath Lake also captures a significant ground-water inflow that discharges into the lake from the regional aquifer. For the 52 yr period of interest, estimated ground-water inflow averaged about 265,000 ac-ft per year. Ground-water inflow that also occurs from unmeasured springs and seeps around the margin of the lake is estimated at 6000 ac-ft per year. For the 52 year period of interest, total ground-water inflow averages approximately 271,000 ac-ft per year.

Losses from Upper Klamath Lake -

For Upper Klamath Lake, the net evapotranspiration from attendant natural marshlands and the net evaporation from the open water surface of the natural lake comprise losses that are supported by the natural inflow to the lake. Marshlands are comprised of lake wetland marsh that is continually inundated by storage in the natural lake, and lake emergent marsh that is subirrigated from ground water that is associated with the natural lake. For the slightly more than 62,500 acres of marshland associated with the natural Upper Klamath Lake, these attendant losses averaged about 85,200 ac-ft per year for the 52 yr period of record. For the same period, net evaporation from the nearly 67,000 acres of open water surface of the lake averaged about 158,500 ac-ft per year. Total loss from the lake, given average annual conditions, is estimated at just less than 244,000 ac-ft per year for the 52 yr period of interest.

Resulting water balance for Upper Klamath Lake and natural outfall to the Link River -

The resulting natural outfall of Upper Klamath Lake is the consequence of total inflow and net loss. For natural lake conditions, the water balance rounded to the nearest thousand acre-feet is as follows:

Average annual natural inflow……………………….. 1,668,000 ac-ft
Average annual natural net loss ……………………... 244,000 ac-ft

Resulting average annual natural outfall..…………… 1,424,000 ac-ft

This result is comparable with the simulated average annual natural outfall of Upper Klamath Lake which includes the annualized residual storage carried in the final time step of the simulation.

<u>Lower Klamath Lake and its natural outfall to the Klamath River at Keno</u> –

The balance of the natural inflow to Lower Klamath Lake and attendant losses from the associated marshlands and the open water surface of the lake will result in natural outfall from the lake to the Klamath River at Keno. Inflow to the lake from the natural flow of the Link River, and some ground-water inflow, is therefore supporting these losses. The magnitude of each factor in the water balance may be described by examination of the resulting water-balance for the lake.

Natural inflow from the Link River and measured predevelopment ground-water inflow –

As developed in the preceding section, the natural outfall from Upper Klamath Lake is the source of nearly all of the natural inflow to Lower Klamath Lake. This inflow averaged about 1,424,000 ac-ft per year for the 52 yr period of interest. As mentioned in a report dated December 26, 1908, by J. H. Quinton, consulting engineer to the USRS, L. W. Hall, a Reclamation Service engineer, had measured more than 100 cfs total discharge from springs on the south and west shores of Lower Klamath Lake. This ground-water inflow to the lake is about 72,400 ac-ft per year. Resulting natural inflow to Lower Klamath Lake was therefore about 1,496,000 ac-ft per year.

Losses from Lower Klamath Lake –

The net evapotranspiration from attendant natural marshlands and net evaporation from the open water surface of the natural lake comprise losses supported by natural inflow from ground-water and the Link River. Marshlands are solely comprised of lake wetland marsh that is continually inundated by storage in the natural lake. For the slightly less than 56,000 acres of marshland associated with the natural Upper Klamath Lake, these attendant losses averaged about 96,000 ac-ft per year for the 52 yr period of interest. For the same period, net evaporation from the nearly 35,000 acres of open water surface of the lake averaged nearly 92,000 ac-ft per year. Also, overflow from Lower Klamath Lake (Lake Ewauna) through the Lost River Slough, averaged about 6,000 ac-ft annually for the 52 yr period of interest.

Resulting water balance for Lower Klamath Lake and natural outfall to the gage at Keno –

The resulting natural outfall of Lower Klamath Lake is the consequence of total inflow and net loss. For natural lake conditions, the water balance for the average year, rounded to the nearest thousand acre-feet, below, includes an estimated measured pre-development ground-water accrual to the lake.

Average annual natural inflow………………………..	1,496,000 ac-ft
Average annual natural net loss ……………………...	188,000 ac-ft
Average annual overflow, Lost R. Slough …………...	6,000 ac-ft
Resulting average annual natural outfall..……………	1,302,000 ac-ft

<u>Discussion</u> –

The process developed for the water budget for evaluating the undepleted natural outfall of Upper Klamath Lake appears to adequately account for factors related to water-resources developments in the watershed that have affected inflow to the lake, and for losses due to natural condition of the lake. Watershed conditions were examined and changes in streamflow due to irrigation of croplands were evaluated. Simulated outfall from Upper Klamath Lake was based on a conceptually straightforward explanation of the dynamic response of the lake to net inflow and storage within the lake as a natural water body. Records used in developing this analysis, which is an empirical assessment, were derived from both stream gaging flow histories, and from climatological records for stations within and adjacent to the study area. Information was also developed from published reports, file documents, and maps. These sources of data are reasonably diverse and the processes used are conceptually well based and sufficient that the result of the analysis seems adequate and representative. A critical example showing this statement is reasonable is in regard to changes in watershed condition of the Sprague and Williamson Rivers (other than irrigated agriculture) and the net affect on streamflow. As these changes are progressive and cumulative, the net impact of these changes, if evident, would appear in the double mass and trend analysis that was completed comparing the calculated natural flow of the Williamson with the gaged natural flow of the Rogue. In that comparison, the trend in the normalized natural flow of the Williamson was shown to be consistent and comparable with the trend in the normalized annual flow of the Rogue.

Resulting elements of the simulation can be examined to determine if the response of the lake and resulting outfall is consistent with historical experience. One of the fundamental problems in this comparison, however, is that historical experience with the natural lake was during a series of years early in the 20th century when inflow to the lake was consistently about 1.35 times the average indicated for the period of interest in this study. An element examined for this consistency is the simulated water surface elevation of the lake, as shown in Figure 3. The trace of the time series for monthly average elevation of the water surface does not show any excursions or deviations that are inconsistent with historical experience.

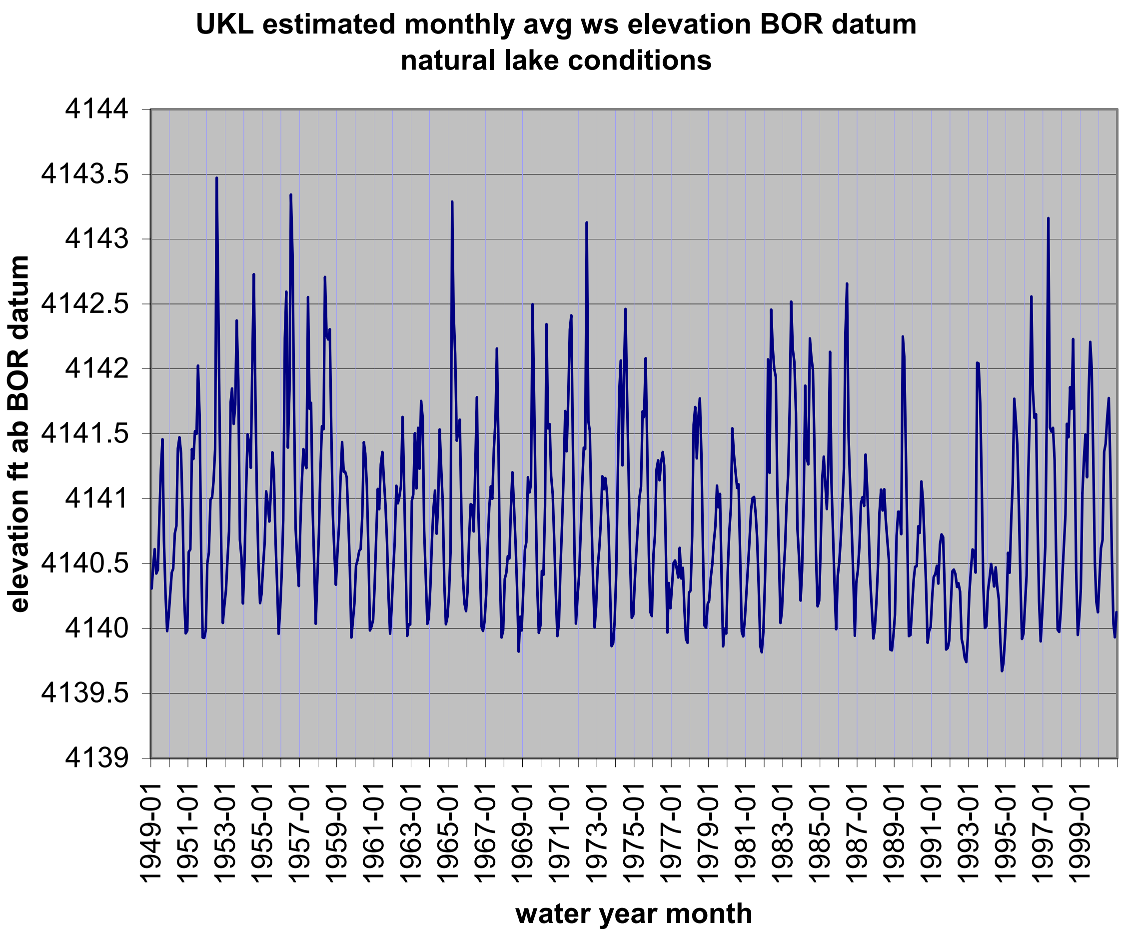

Figure 3. Simulated average monthly water-surface elevation of Upper Klamath Lake estimated for natural lake conditions.

Of particular interest regarding the outfall from the lake is the hydrographic trace for the last half of the period of interest. Results of the analysis show monthly average flows during the summers of 1992 and 1994 are as low as those encountered historically for the natural lake. Further, climatic factors that are causing the declining trend noted for inflow may be responsible for these secular low flows. The hydrographic trace of the inflow and outflow for the last half of the period of interest illuminates the secular nature of the low mid-summer outfall from Upper Klamath Lake, is shown in Figure 4. For years such as 1977, 1981, 1988, 1991, 1992, and 1994, significant late-spring seasonal snowmelt was not evident and the summer season natural outfall from Upper Klamath Lake was minimal. The secular minimum shown in 1992 indicates that *the mid-summer transit loss across the natural lake exceeds 800 cfs*, which is accountable to the nearly 130,000 acres of natural marshland and open water surface that were attendant to the natural lake. The magnitude of this loss may be noted as typical for the natural lake throughout the period of interest from 1949 to 2000.

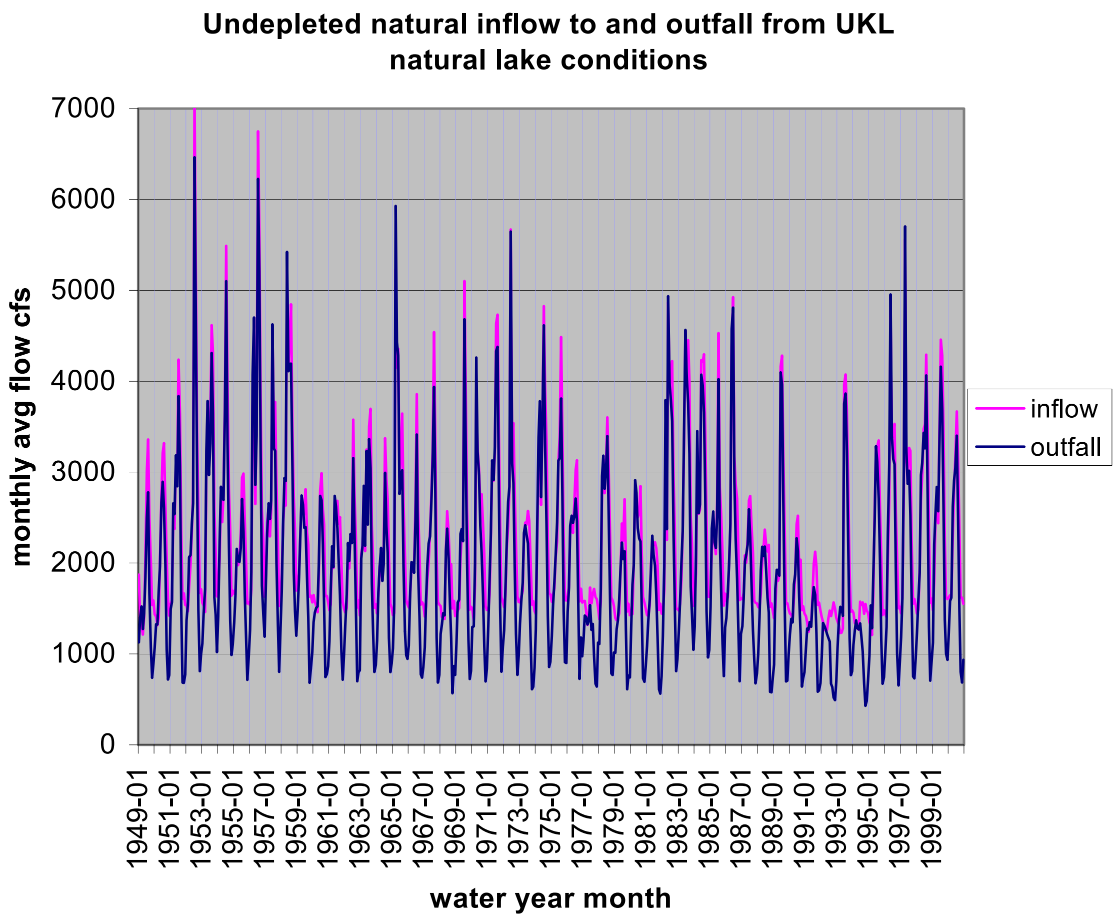

Figure 4. Simulated monthly average inflow to and outfall from Upper Klamath Lake, in cfs, estimated for natural lake conditions.

The process developed for the water budget for evaluating the undepleted natural outfall of Lower Klamath Lake appears to adequately account for factors that affected inflow to the lake, and for losses due to natural condition of the lake. Simulated outfall from Lower Klamath Lake was based on a conceptually straightforward explanation of the dynamic response of the lake to net inflow and storage within the lake as a natural water body. Records used in developing this analysis, which is an empirical assessment, were derived from both stream gaging flow histories, and from climatological records for stations within and adjacent to the study area. Information was also obtained from published maps and reports, and file documents. These sources of data are reasonably diverse and the processes used are conceptually well based and sufficient that the result of the analysis seems adequate and representative.

Resulting elements of the simulation can be examined to determine if the response of the lake and resulting outfall is consistent with historical experience. One of the fundamental problems in this comparison, however, is that historical experience with the natural lake was during a series of years early in the 20th century when inflow to the lake was consistently higher than the average indicated for the period of interest in this study. An element examined for this consistency is the simulated water surface elevation of the lake, as shown below. The trace of the time series for monthly average elevation of the water surface does not show any excursions or deviations that are inconsistent with historical experience.

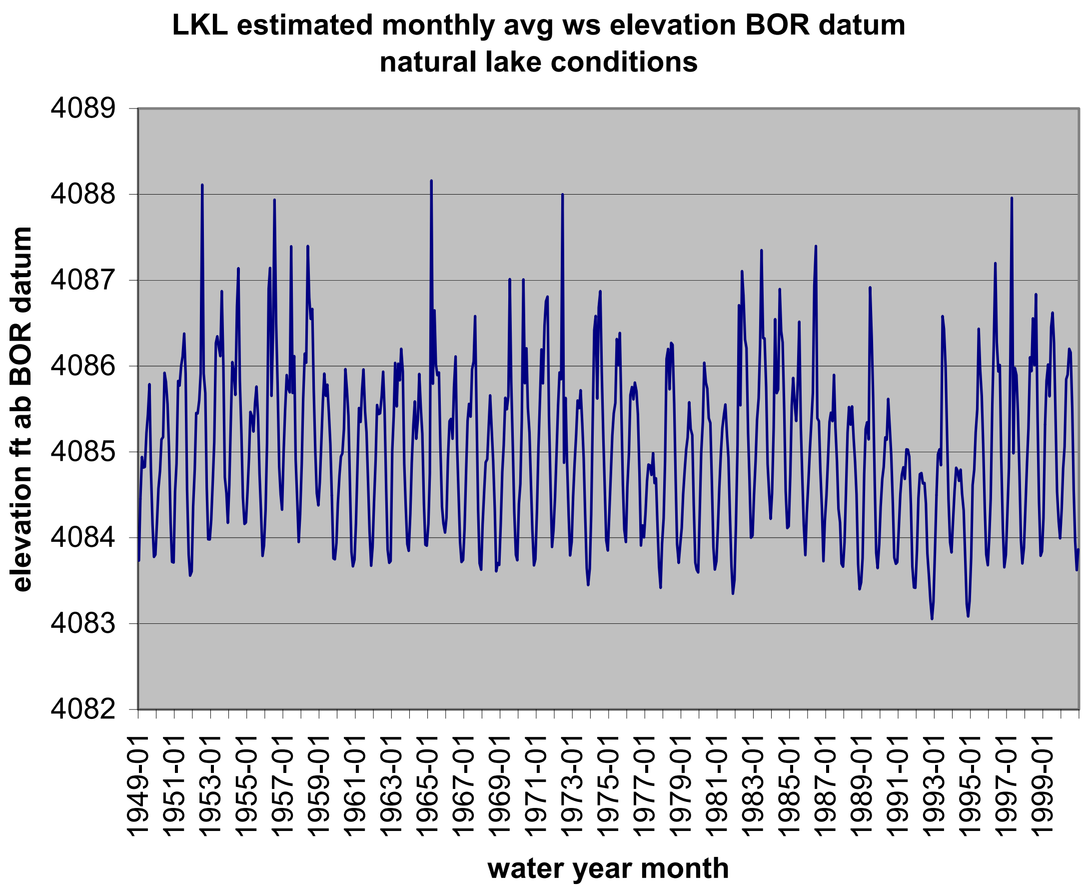

Figure 5. Simulated average monthly water-surface elevation of Lower Klamath Lake estimated for natural lake conditions.

Of particular interest regarding the water-surface elevation for the lake is the hydrographic trace for the last half of the period of interest. Results of the analysis show monthly average flows during the summers of 1992 and 1994 are as low as those encountered historically for the natural lake. Further, climatic factors that are causing the declining trend noted for inflow may be responsible for these secular low flows and the consequent secular low elevations evidenced in the water-surface elevation record.

An examination of the hydrographic trace of the inflow and outflow for the last half of the period of interest illuminates the secular nature of the low mid-summer outfall from Upper Klamath Lake and consequent outfall from Lower Klamath Lake, as shown in Figure 6. For some years, especially 1981, 1988, 1991, 1992, and 1994, significant late-spring seasonal snowmelt was not evident and the summer season natural outfall from Upper Klamath Lake was minimal. The secular minimum shown in 1992 indicates that *the mid-summer transit loss across from the Link River to Keno exceeds 700 cfs*, which is accountable to the nearly

91,000 acres of natural marshland and open water surface that were attendant to the natural lake. The magnitude of this loss may be noted as fairly typical for the natural lake as indicated for many summers throughout the period of interest from 1949 to 2000.

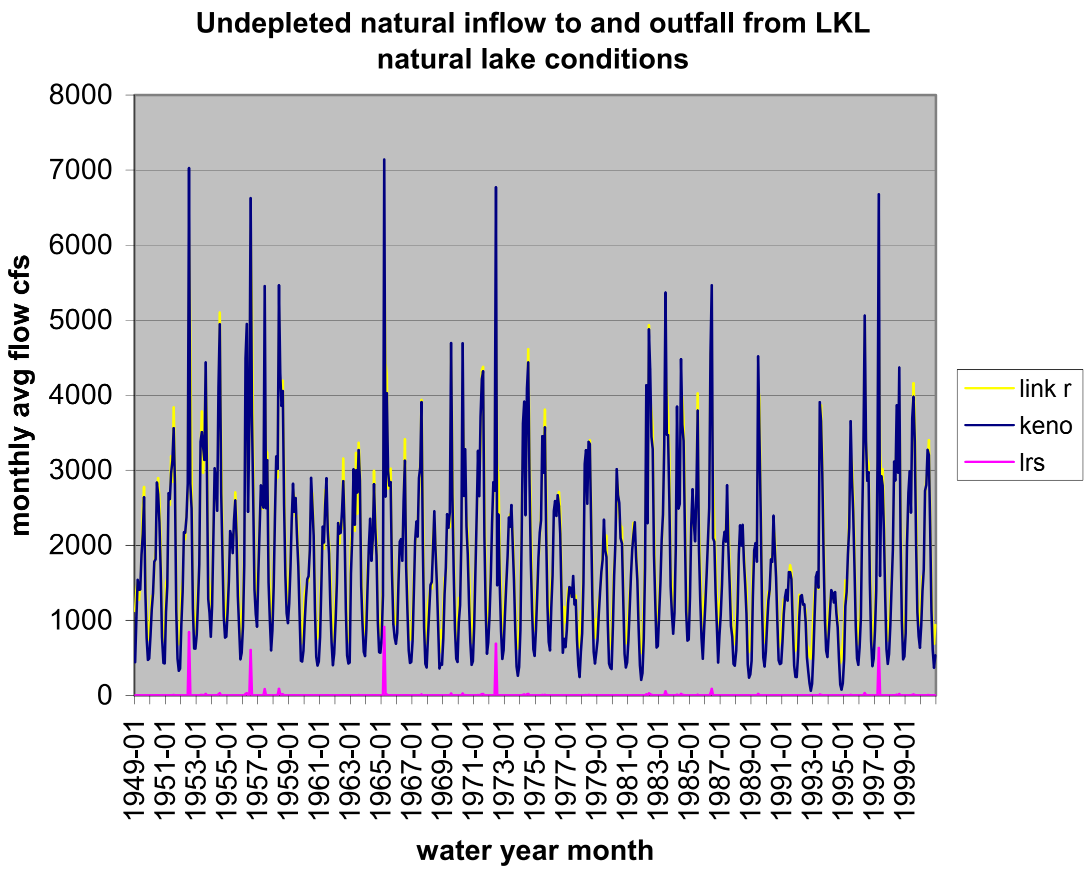

Figure 6. Simulated monthly average inflow to and outfall from Lower Klamath Lake, in cfs, estimated for natural lake conditions. Shown are the Link R. inflow, *link r* (yellow line), outfall at Keno, *keno* (blue line), and overflow through the Lost River Slough, *lrs* (magenta line).

Part 4: Received comments and additional elements in development

Background –

This study was released as an initial draft for review in early December, 2003. Comments received from reviewers addressed specific aspects of the study that needed to be expanded. These aspects related primarily to significant unmeasured ground-water inflow into Upper Klamath Lake, expansion of the assessment of Klamath Marsh and Sycan Marsh, assessment of changes in forest conditions and consequences to natural flows, sensitivity analysis, and extension of the flow histories, among others. Other aspects having similar considerations were seen by the seven investigators preparing the natural flow study. These considerations are related to possible climate-signature adjustment of ground-water discharges into the headwaters of streams in the Wood River Valley, continued internal quality control and data validation, and comparison of natural flows developed in this study to other nearby natural flow histories, and to the present-day gaged-flow history of the Klamath River.

Ground-water investigations –

Comments received indicated one principal area of investigation, namely significant unmeasured ground-water contributions to Upper Klamath Lake, needed to be expanded for inclusion within the study. Aspects of this comment and related issues indicated the investigation needed to be expanded further to include a climate signature adjustment to ground-water inflow to the Wood River and Crooked Creek, and to Upper Klamath Lake. The incidental recharge to the active ground-water system of the Wood River Valley also needed to be addressed. This ground-water contribution would generally accrue to the lake through the Wood River and Sevenmile Creek.

- *Upper Klamath Lake*

Comments received indicated that significant unmeasured ground-water inflow was evident for Upper Klamath Lake. This aspect had not been addressed in the natural flow study. The principal published source of information regarding this inflow was indicated by the comments to be a USGS report by Hubbard (1970), which had been initially reviewed. The method used by Hubbard for the determination of this unmeasured ground-water inflow was seen as fraught with errors and the results were unreliable. Therefore, results by Hubbard were not initially included. A re-evaluation of Hubbard's work substantiated the impression regarding error given in the initial review of that work. To include information in Hubbard's work and develop the unmeasured ground-water inflow, Hubbard's entire analysis was re-examined using correct information and appropriate methods. Results of that analysis are included within this report, but still require climate signature adjustment as needed. The re-evaluation of Hubbard's work was assisted by file materials that were provided by the USGS WRD Oregon District Office, in Portland. Currently, the calculation process is being examined and the implementation methodology is being evaluated.

- *Wood River, tributary inflow from Fort Creek, and Crooked Creek.*

Among aspects evident in the review of comments was the need to temporally adjust headwater spring-discharge accruals to the Wood River, tributary inflow to the Wood from Fort Creek, and inflow to UKL from Crooked Creek. This temporal adjustment is attributable to the climate signature evident in longer term records for similar ground-water discharges in neighboring watersheds. Temporal adjustment of ground-water inflow may also be applicable to other aspects being evaluated for the natural flow study.

- *Natural incidental recharge to active ground-water system in Wood River Valley*

An apparent aspect being examined involves natural incidental recharge in the Wood River Valley, and drainage of this ground water to streams forming hydraulic boundaries, or to Upper Klamath Lake. Drainage of natural recharge to the Wood River and Sevenmile Creek would provide additional inflow to Upper Klamath Lake.

<u>Revised assessment of Klamath Marsh, Sycan Marsh</u> –

Comments indicated the need to adequately estimate the timing of flows in the Upper Williamson below Klamath Marsh. Spring-season inflow to the marsh may be seen as being stored within the marsh as a natural lake. Outflow from this lake to the Williamson evidently occurs during the maximum inflow period in the early summer, while marshland evapotranspiration depletes storage in the mid summer. Because inflow is primarily snowmelt driven in the late spring and early summer, in addition to seasonal ground-water accruals that are substantial, depletions consume available water that would discharge to the Williamson during the mid-to-late summer season. As the marsh becomes senescent during the late summer, these depletions decline. During the late summer, and into the early fall, ground water slowly fills depleted storage within the marsh and discharge to the Williamson gradually resumes. Currently, Klamath Marsh is being evaluated to determine the natural hydraulic elements that would comprise the marshland lake. Aspects of the investigation of Klamath Marsh will include developing the natural inflow to the marsh from the Williamson and from ground water that discharges into the marshland area.

Comments also indicated the need to examine in greater detail the changes in Sycan Marsh from its natural condition. Because information regarding irrigation developments in Sycan Marsh is unavailable due to water-rights proceedings and the Alternative Dispute Resolution process, provision of requested data from participants who have made these comments would assist in evaluating this aspect of the investigation. While Sycan Marsh has changed character relative to natural conditions due to historic grazing practices, observations by The Nature Conservancy indicate that a detailed examination of the natural flow from Sycan Marsh probably would not yield significant increases to the flow exiting the marsh as compared to flow that has occurred under the managed condition. The net evapotranspiration rates from the natural-marsh vegetation that existed prior to development were likely similar to or slightly higher than net evaptranspiration rates of the vegetation that existed under the managed condition (L. Bach, pers. comm.). A more detailed examination of the marsh may likely indicate that under natural conditions, due to evapotranspiration from the greater total area of natural marsh compared with that existing presently, outflow from the marsh may have been less than at present. The objective evaluation, analysis, and assessment of the requested data will allow the significance of this difference from the natural condition of the marsh to be determined.

<u>Changes in forest conditions: pre-development vs. present-day watershed yield</u> –

Comments received indicated the need to examine present-day watershed conditions with regard to watershed yield for corresponding pre-development conditions. Present-day watershed conditions may be causing a decline in watershed yield due to fire suppression. Encroachment by juniper may be exacerbating this consequence. Other changes from natural conditions, such as beaver extirpation, forest clear-cutting, and land clearing, may be increasing flows by increasing watershed efficiency, but may be causing a decline in base flow. Present standing of the natural flow study does not address these changes. These comments were, therefore, very appropriate and incisive.

- *Fire suppression*

Addressing fire suppression requires understanding several key concepts used in defining the natural flow study. Pre-development conditions, for instance, may be defined as embracing those watershed conditions exiting before settlement began. However, when settlement was initiated, development did not immediately begin or become significant and changes in watershed environmental conditions were not immediately evident. Therefore, pre-development conditions also embrace a part of the settlement period that began after about 1850. Development conditions, in general, began about 1870 and were established by 1910. At about this time, however, fire suppression was initiated because large, uncontrolled forest fires posed a considerable threat to persons and property. Pre-development watershed conditions fundamentally came to an end at that time. Even so, the consequence of changes in watershed condition was not immediately evident because the environmental condition of forested areas was a relict of pre-settlement conditions. Prior to settlement, forest environmental conditions had been, in many ways, effectively managed through somewhat controlled burning initiated by Native Americans (see Leiberg, 1900, 1902). This alteration in watershed conditions by Native Americans, particularly east of the Cascades, was ubiquitous. Hence, even before settlement, watershed environmental conditions were not natural. Pre-settlement human activity had affected the environment on a landscape-scale and indicates that the ecological balance and watershed conditions existing within watersheds east of the Cascades was fundamentally different than those existing naturally. In short, natural conditions did not exist.

Within the objective of this report, the term *natural* is indicative of watershed conditions existing during the pre-development period. The term *pre-development* describes a period of time or watershed conditions existing during the settlement period. These are the same conditions that existed during the pre-settlement period. Watershed *environmental* conditions fundamentally changed with fire suppression beginning about 1910, and the last vestige of pre-development watershed conditions was probably gone by about 1960. Only within remote alpine and some sub-alpine watersheds are present-day environmental conditions similar to those existing before settlement began.

Addressing the change in forest cover is the principal element being evaluated regarding fire suppression and the impact to present-day watershed environmental conditions. Watershed yield for drier forest conditions may have changed little in the absence of fire. However, the influence of fire suppression may be coupled with other factors that have affected watershed yield. The focus of the current study, however, was to address the effects of agricultural development landscape and on natural streamflow.

- *Juniper encroachment*

Western Juniper favor xeric to aridic soils where soil moisture and climatic conditions indicate winters are cool and moist, and summers are dry. Annual precipitation is generally between 10 and 20 inches annually for areas favored by juniper. These trees predominantly favor terraces and flood plains, grass-shrub uplands, and rolling topography that is generally less than 5000 ft in elevation. Farther south, these trees favor similar conditions in an elevation band between 5000 and 8000 ft.

The 1930s USDA survey of forest resources in Washington and Oregon shows little or no juniper within the watershed area producing inflow to Upper Klamath Lake. Nevertheless, within eastern Oregon the encroachment of juniper has been significant since about 1880. Although the reasons for encroachment are not clear, the proliferation of juniper may be related to changing climatic conditions, increases in grazing, and fire suppression. Milder climatic conditions existing after about 1850 produced a more favorable environment that enhanced the growth and succession of juniper throughout the savanna and chaparral of eastern Oregon. Grazing, beginning about 1860 and increasing through the early 1900s, influenced the expansion of juniper by reducing grasses and other finer fuel producing ground cover that would have provided fire-clearing of younger plants and thereby limited the expansion. Fire suppression, of course, enhanced the expansion of juniper by eliminating fire as a significant element in the natural environmental control of juniper.

Within the study area, juniper does not occur within portions of the watershed that produce significant inflow to Upper Klamath Lake. Juniper expansion also does not appear to be significant within this part of the watershed during the post-settlement period. Evidently, no change in watershed conditions can be substantiated regarding encroachment of juniper.

- *Beaver extirpation*

Somewhat conflicting indications are found regarding the presence of beaver as significant within watersheds that are tributary to Upper Klamath Lake. Robbins and Wolf (1994) quote a version of Ogden's journal for 1826-27 (as edited by M. A. Davies, 1961) indicating beaver had already been extirpated at the time Ogden ventured through the region. Although Ogden found few beaver, one of his party (McKay), sent to trap in the Cascades west of Upper Klamath Lake, is reported to rejoin Ogden's returning party a short time later and had trapped several hundred beaver and otter. These results, however, appear in an earlier 1905 transcription, *supposedly of the same journal*, copied by A. C. Laut from the original in Hudson's Bay Company House, London. In general, reading through Laut's transcript, Ogden's demeanor regarding the extirpation of beaver seems motivated by his frustration and his ill health at the close of his southern Cascade venture, one for which he had hoped would have given him a better reward and better showing for his employer. Nevertheless, there seems to be little objective evidence suggesting beaver had a significant presence in the Upper Klamath watershed.

- *Forest clear-cutting*

Clear-cutting in forested areas can, potentially, increase streamflow. Well managed forest practices, however, will limit the size of the cut area and thereby limit the impact to runoff generated from the watershed. Within the moist, western slope area of the Cascades, forest regrowth is more rapid and clear-cut logging is therefore more intense. Logging is generally limited in the climatically drier, lower yield forested areas east of the Cascades as regrowth of clear-cut areas is slower. Within these drier areas, much of the logging activity may be related to thinning or selectively cutting older trees. Drier conditions, smaller clear-cuts, or selectively cutting and thinning older trees, may have a very limited impact to watershed conditions and may produce little or no effect on streamflow.

Recovery of flow history to 1905 -

Extension of the flow history for the Link River and Keno gages would require reconstruction of the pre-1949 missing portions of precipitation and temperature histories used in the analysis, and flow histories of watersheds along the east flank of the Cascades. Prior to 1949, longer-term records that may be used in these reconstructions become increasingly limited. Consequently, several of the climatic records with longer missing periods ultimately become surrogate reconstructions of one, or two, stations that have long, continuous records. This is also true, more or less, of watershed flow histories. The end result derived from using such reconstructions may not be as representative as that from more recent records that were reconstructed and used in the computation of evaporation, consumptive uses, and inflow to UKL.

- *Extension of natural flow to, and below, Iron Gate*

Some of the comments that were received indicated that extending the flow estimates to Iron Gate, and perhaps farther downstream than Iron Gate, were desirable. The natural flow between Keno and Iron Gate has already been determined and is available in KPSIM (an excel spreadsheet) contained within a special file.

Sensitivity analysis –

As stated by Emshoff and Sisson (1970), a common method for validating a simulation is to compare the output of the simulation model to historical data, or previous actual behavior of the system, under similar environmental conditions. In a sensitivity test, one or more factors are changed to determine a) if they affect the output and b) if they help make the model produce results that more closely match historical data. The question being answered is whether the subsytem models, or modules, are valid. Put another way, *is the hypothesis valid?*

Sensitivity analysis works well to check the calibration of a model, or to determine which factors in the model need to be adjusted most effectively to achieve calibration. Overton (1977) states the proposition this way:

> Consider now the manner in which modular construction can reduce the amount of work in sensitivity analysis. For a model with two inputs, two outputs, and four parameters, prescribe an incremental change in each parameter. Examination of this response requires four runs with the parameters varied individually, six runs with the parameters varied in

pairs, four runs with the parameters varied in groups of three, and one run with four varied together. Altogether we find $2^k - 1$ runs required for incremental perturbation of k parameters. Study of both directions ($\pm \Delta$) of the neighborhood requires $3^k - 1$ runs.

Overton (1977), continues to say that in such an analysis the higher-order runs are seldom made simply for reasons of economy. This decision involves, to some degree, tacit assumptions of non-interaction among the parameters or the acceptance of such interactions as unimportant. If these assumptions are actually made, the implied modular structure of the model can be recognized. Instead of $2^k - 1$ runs, only $2(2^{k/2} - 1)$ runs if the two subsystems are equal in number of parameters. For the four-parameter model, then, the number of runs has been reduced from 15 to 6. Overton also mentions a way to obviate even this task if the model can be decomposed into a modular series where input elements used simultaneously in each of the modules may be varied to assess the effect.

The four-parameter model mentioned above is similar to certain of the individual computational modules used in construction of the water budget. The evaluation mentioned by Overton is the same process that would be used for the natural flow model. Decomposition of the natural flow model into separate modules that would allow a sensitivity analysis would require all of the modules to be integrated into the spreadsheet. To do this would require a complete reassembly of the model with all of the exterior components that were used. The advantage in doing this, however, would allow an immediate comparison of results for changes in any parameter. If the model was redeveloped as a simulator, which is essentially a computer program, each module of the simulator, and every parameter used in the simulation, could be checked and the effect on results assessed. Use of a simulator would be much easier than completion of the same using Excel, but the results would be much less transparent. Nevertheless, *completing* the sensitivity analysis would still require sufficiently contemporaneous historical data against which the computational results may be compared. For example, net evapotranspiration from crop irrigation, as developed with the Blaney-Criddle method, is dependant upon temperature, precipitation, and a developed crop coefficient. There are, however, no in-field data collection platforms collecting real-time climatic information that would allow a more accurate and highly dependable estimate of net evapotranspiration. Methods are in place, such as Penman, for calculating estimated et values from such real-time data. Therefore, without such an estimate there is no concurrent, longer-term data history against which to compare the results of the Blaney-Criddle procedure. Assessment of the variation in parameters, such as temperature, precipitation, or crop coefficient, would only be indirectly meaningful. The only alternative would be to compare the Blaney-Criddle results with those of another method that has been shown to produce a better evapotranspiration estimate that is more consistent with real-time data.

Precision and reliable accuracy of the estimates –

Precision carried in the calculations retains the full number of significant digits of each of the operand elements. Resulting quantities are therefore over-specified regarding accuracy and the reported values of these quantities exceeds their reliable accuracy. Calculations have been carried through to the most number of significant figures provided to allow the results to be traced, or specific quantities to be identified. Quantities presented in the spreadsheet

ukl.lkl_simulation should generally be considered representative to no more than about three, or in some cases, four significant figures. As a general statement for the spreadsheets used in this study, *the precision reported exceeds the reliable accuracy of the estimates*.

Internal quality control and validation –

Presently, consistency in data elements and revision as needed is being evaluated for the flow histories of Annie Creek, Sevenmile Creek, Cherry Creek. Updated and more accurate determinations are being incorporated in the simulation spreadsheet from supporting spreadsheets for evaporation and crop evapotranspiration.

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References for Historical Conditions (with some annotation)

LRS = Lost River Slough
LKL = Lower Klamath Lake
UKL = Upper Klamath Lake

UKL/LKL: Abbot, Lieut. Henry L., 1857 Explorations and Surveys, to Ascertain the most practicable and economic route for a railroad from the Mississippi to the Pacific Ocean, 1854-5, The Sacramento Valley to the Columbia River, War Department, Washington, Government Printing Office, p.
Contains descriptions of area by early explorers. See Part 1, p.28 "The chain of Klamath water is an interesting feature of this region. ….Colonel Fremont, in his expedition of 1843-44, crossed the principle tributary to this [Klamath] marsh. He describes it as a stream thirty feet wide, and from two to four feet deep. …After passing through a canon…it spreads out into a fine sheet of water, called Upper Klamath Lake. This lake receives several smaller tributaries. The river leaves it near its southern point, and soon wind through a marsh, which forms the northern portion of Lower Klamath Lake. Lieut. Williamson, with a detached party, examined this portion of it course, and his opinion was, that in seasons of high water the marsh is overflowed and the river can properly be said to flow through the lake. In summer, however, its bed is very distinct, and it does not join the sheet of water forming the lake." Page 66-72 have some descriptions of lake area. Chapter IV LKL Williamson explorations Page 76-77 "August 14 …skirted western side of the lake… The body of water was small, but a large marsh extended for about 10 miles towards the north." "August 15 … The river comes into the marsh, curves through it, and passes off to the canon, without any visible connection with the main body of the lake, which lies further southward. Doubtless, in the rainy season, the water covers the whole marsh, and then the river literally passes through the lake." "August 16- …came at noon to an arm of a large lake from which the river flowed. This proved to be Upper Klamath Lake. It was difficult to say where the connecting river ended and the lower lake began. Where the tules ceased, the river ran rapidly between low hills backed by higher ridges and was full of rapids. In one place there were falls from five to ten feet high. We found the river everywhere too deep to ford. At the rapids, where many rocks rose above the water, there were numerous deep holes; and near where it emerged from the lake it was twenty feet deep."

Part III, Botanical Report, Chpt. 1 p.17 Shores of the Klamath Lakes. "The immediate borders of the lakes are covered with a growth of tule… On drier ground but still in the vicinity of the water, are thickets composed of *Pyrus rivularis, Prunus subcordata, Rhamnus Purshianus,* and wild cherry… The number of trees in this vicinity is small. A few cottonwoods and willows are found in the neighborhood of the water…"

LRS: Abney Robert, M., 1964, A comparative Study of the Past and the Present Condition of Tule Lake, Bureau of Sport Fisheries and Wildlife Tule Lake NWR, Tule Lake California. Provided historical information on Lost River Slough (p.3 – "A flood in the spring of 1890 gushed Klamath River water down Lost River slough deep enough to swim a horse for about six months and brought Tule Lake to it's last historic high water level of 4064'". "…the Klamath River periodically flooding down the Lost River Slough is the main source of water which caused Tule Lake's historic high levels. The natural control of this Klamath River flowage into Tule Lake was regulated by the amount of spill over the reef from Upper Klamath Lake and the amount of river flowage over the rapids at Keno". P.5: "Even with the lake level at 4076', Tule Lake was about 10' lower than the Klamath River and served as a storage reservoir of Klamath River water via the Lost River Slough". p.6:"Following the high water of 1890, J Frank Adams, Jessie D Carr and a company of Tule Lake ranchers built a mile long dike along the east bank of the Klamath River to stop the flow of Klamath River into Tule Lake via the Lost River Slough and Lost River.")

UKL/LRS: Atkins, Glen, J. 1970, The Effects of Land Use and Land Management on the Wetlands of the Upper Klamath Basin, MS Thesis Western Washington State College, 122p. Has discussion of preexisting wetlands, LRS, physical setting, vegetation, and historical development.

LKL (/UKL): 1965, As told to me… Klamath Echos, 1(2):11,
"By the summer of 1905 we find Mr. Woodberry associated with M. G. Wilkins in the Klamath Navigation Company, which launched the steamer on August third for service between Klamath Falls and Lairds Landing on Lower Klamath lake. At this time the McCloud the McCloud Railroad was building toward that point, and the steamer became a link in the following transportation system: Steamer Klamath from Klamath Falls to Lairds Landing (50 miles)…". "As told to me… by George Stevenson April 12, 1953": "I bought the old dredge from Southern Pacific in 1914. They had used it building the Ady fill across Lower Klamath Lake. Must have moved it to the Upper Klamath Lake about 1908. Its name was the Klamath Queen. The Southern Pacific used it on their right of way along the Upper Lake. I bought it after the work was finished. I used it on building dykes; built about one hundred miles of dykes on the Upper Lake and Agency Lake."

LKL: 1965, As told to me…by John Yaden, February 3, 1948. Klamath Echos 1(2): 20-21
"I came here in 1901.

…It was for the steamer Klamath that the channel was dredged to Laird's Landing. Previous to this all landings had been at Mosquito Point, about two miles northeast of Laird's and Chalk bluffs about one mile further.

I ran both the Ewauna (40 feet in length) and Tule (25 feet in length) on Lower Klamath and used the Adams Tule Cut into White lake in carrying Reclamation officials to various places. There was also a landing northwest of Lairds, 1 ½ to 2 miles where no dredging was necessary for boats to land. This may have been called Indian Bank landing…

may also have been called Coyote Point or Oklahoma Landing I later times. Theer was another landing reached through Sheepy Lake that required no dredging. This landing was the one possibly used by the Fairchild Ranch". (see 1905 maps for places and possible inference of date)

UKL-LKL: Boyle, John C. 1976, 50 Years on the Klamath, Klocker Printery, Medford, OR, 59p.
(Information on project history, e.g. 1918)

UKL: Carlson, J.R., 1993, The Evaluation of Wetland Changes around Upper Klamath Lake, Oregon, Using Multitemporal Remote Sensing Techniques, Chapter 6 in Campbell, S.G., editor, Environmental Research in the Klamath Basin, Oregon 1991 Annual Report, USDI BOR, Denver Office, R-93-13, 212 pp.

LRS LKL UKL: Cleghorn, John C., 1959, Historic Water Levels of Tulelake, California-Oregon and their Relation to the Petroglyphs, Klamath County Museum Research Papers, No. 1, 11p.
This provided information ion the Lost River Slough and also comments about reefs at UKL and Keno (p.2) (i.e "overflow did not occur [at keno] except in flood times". Reference to making a survey of LKL in 1908 "before it was drained" (p.6).

UKL/LKL: Gatschet, Albert Samuel, 1966, An Extract from the Klamath Indians of Southwest Oregon (facsimile), Ethnographic Sketch of the Klamath Indians of SW Oregon (From Contributions to North American Ethnology, Vol. 11, Part 1, Washington DC, Government Printing Office, 1890.

LKL: Helfrich, W.H. 1965, As told to me…by Judge U.E. Reder, Recorded March 3, 1948. Klamath Echos 1(2):18-19: "I came here in 1895 and began boating about 1900.

They just piled the freight up and we would take two fifty-ton barges to bring it back…. Most of the lumber used in building Merrill and the surrounding ranches was brought ion by boat from McCormaks Mill at Keno to White Lake, not by wagon as most people think.

We always tried to haul lumber to the lower lake in the spring when the water was running through the straits into Lower Klamath Lake. And in the fall, we hauled hay from Oklahoma through the straits into the river, when the water was draining out of the Lower Lake. … On White Lake there used to be humps all over and what time we were not stuck in the mud, we were out in hip boots hunting a channel."

The Van Brimmer ditch drained White lake so far that Frank Adams attempted to get water from Lower Klamath. At first he tried to open up a channel from Lower Klamath Lake by cutting the sod with hay knifes, but it didn't work. So later he got a dredge… The Adams dredge was used on Adams cut from Lower Klamath Lake to White Lake, on the cut to Laird's Landing and on the fills for the railroad across the swamp at Ady. It was also used south of town here dyking Lake Ewauna.

…"The Canby or its barges never drew more than three feet of water if that much. They were flat bottomed, so they could go over the old Indian rock ledge near the Kesterson mill."

FISH RUNS: *Klamath Republican*, March 21, 1901: "Those who like to see fish, immense congregations of them…ought to be here now. …These enormous drove of fish can now be seen not alone here, but in the rivers and creeks generally throughout the country. Mulluts, rainbow trout and salmon-splendid fish, giants of their size and apparently anxious to be caught. This phenomenon will last a month, and until their egg-laying camp meeting is over with. After that the fish will be distributed over a wider space and will be in plenty the year through."

LKL: *Klamath Republican* June 8, 1905: "The boat [Klamath] is 75 feet long with a 16 foot beam. The hold has a depth of four feet. It draws three feet, two inches of water, and will carry about 75tons."

LKL: *Klamath Republican* October 12, 1905: "…the *Klamath* would make a trip to the Lower Lake in a few days. Next week they would begin regular round-trips daily between Laird's Landing and Klamath Falls…" Republican October 26, 1905: "The steamer *Klamath* started Monday, on tri-weekly trips to Laird's Landing…"

LKL: 1965, Klamath Echos 1(2):66-67.

"Merril Landing may have seen use during high water seasons, by boats of shallow draft, even before 1903"

"WHITE LAKE CITY LANDING. Founded in 1905, White Lake City probably had a landing of sorts at certain times of the year for a short period of time."

"OKLAHOMA LANDING. At Coyote Point, north of Laird's Landing about three miles. Received lumber and supplies for homesteaders…beginning about 1889."

SHEEPY LAKE LANDING. …supply point on Sheepy Creek, which ran into Sheepy Lake, which in turn connected with Lower Klamath Lake"

"LAIRD'S LANDING. …not opened to water traffic until the late summer of 1905. And then only after a channel was dredged from the open water of Lower Klamath Lake… saw considerable freight traffic use for a few years also, or until the spring of 1908, when railhead had reached Mt. Hebron and Dorris and the traffic then went the way of Teeter's Landing"

"TEETER'S LANDING. About four and a half miles south of Keno, it came into existence by 1889 or before.

…But the end was in sight, on January 1, 1909, Teeter's Landing or Blidel, was bypassed be the new shipping point of Holland, where the railroad crossed the Klamath Straits, running out of Lower Klamath Lake. … There was another "Holland" in western Oregon, so the name Ady came into being."

UKL: Landrum, Francis S., 1988, Guardhouse Gallows and Graves, (About Fort Klamath Area)

LKL: Marcotte, Joseph B, 1968, Lake Stage Determination for Lower Klamath lake (1904-1917), Letter to USBR Files, 4p.
(Has info on Keno gage readings and LKL surface elevations, comments on letter indicate "…Keno gage readings represent very closely the lake levels…" Has figure with LKL elev vs Q at Keno (drawing number 12-201-4448)).

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UKL: Riseley, John C. and Laenen, Antonius, 1999, Upper Klamath Lake Basin Nutrient-Loading Study-Assessment of Historic Flows in the Williamson and Sprague Rivers: US Geological Survey Water-Resources Investigations Report 98-4198, 22p.

LINK: *Sacramento Bee* 2/26/1959
Article mentions that in Gatschet "of Indians scooping up fish from the dry bed of the stream when south wind stopped the waters from flowing from the lake to the river" This quote taken from newspaper referencing Spier's Klamath Ethnolography (Sacramento Bee 2/26/59?) from Klamath County Museum. Also in this article was a quote from William Clark, "who was piloted about the area by the late Captain Oliver C Applegate…"The peculiar fact is that Link or Yulalona River is occasionally blown nearly dry and the water is blown back into the lake when a strong south wind blows". Ray Telford and others here before the time the … built a power dam across the Link River confirm this report. The rushing waters of Yulalona [Link] River actually were held back in the lake as the wind roared up the canyon…"

Spier Leslie, 1930, Klamath Ethnogeography, University of California Publications in in American Archaeology and Ethnology, Vol. XXX, 338 pp.

LKL LRS: USBR, 1910, Specifications No. 170 Accession No. 12379, Drawing No. 1 and 2, July 1910, in "Advertisement, Proposal and Specifications, Klamath Project, Oregon-California, Lost River Diversion Channel".
Original construction drawings for Lost River Diversion Channel Canal. Shows dike of 1910 on Klamath River side of LRS, shows profile along route of channel as well as River water elevations. Also shows RR connections across LKL July 1910 (on location map).

LKL: USBR, 1944, Klamath Straits Drain Outlet Maps 12-D-393, 12-D-385, 12-D-383, and 12-D-384, Klamath Project Oregon California Tule Lake Division Modoc Unit.
Original re-construction drawings for Klamath Straits Drain. Provides some information on depth of straits drain (original ground surface was probably "base of mud" as shown on plans. Drain was dry from 1917 to 1944 when reconstruction began (Jim Bryant pers comm.).

LKL: Voorhees, I.S. 1913, History of the Klamath Project Oregon-California from May 1, 1903 to December 31, 1912, 175p.
Contains description of marsh lands, keno cut, natural reef at keno (4084'), and reference to Quiton's 1908 report.

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Appendices

Appendix 1-1X: Calculation of natural marsh and cropland evapotranspiration

Terms –

(1) Potential consumptive use (CU) or evapotranspiration (ET): The unit amount of water consumed on a given area in the transpiration, building of plant tissue, and evaporation from adjacent soil, water surface, snow, or intercepted precipitation in any specified time. The term includes effective rainfall. Consumptive use may be expressed either in volume per unit area such as acre-inches or acre-feet per acre, or depth, such as in inches or feet.

(2) Effective precipitation (EP): Precipitation occurring during the growing period of a crop that becomes available to help meet the consumptive water requirements of the crop. It does not include rain which is intercepted by the plant canopy and evaporates, surface runoff, or deep percolation below the root zone.

(3) Net Consumptive Use (Net ET): The quantity of water, expressed as a depth or volume, exclusive of effective rainfall, that is consumptively used by plants or is evaporated from the soil surface during one calendar year. It does not include incidental depletions nor does it include water requirements for leaching, frost protection, wind erosion protection or plant cooling. The net consumptive use (Net ET) may be numerically determined by subtracting effective precipitation from potential consumptive use.

Background –

A key part of a complete analysis to flows in stream system is the determination of evapotranspiration of the water used by the local vegetation and land uses. This is an output variable found in the water balance equation where inflows + local precipitation – evaporation and evapotranspiration = outflows. In this section the evapotranspiration (ET) component will be discusseded and examined closely.

Main factors influencing ET are climate, vegetation (crop) characteristics, and environmental conditions. Climate factors are precipitation, air temperature, air humidity, solar radiation, and wind speed. Plant crop characteristics such as leaf area, albedo, rooting characteristics, and ground cover also affect ET as well as the local climate characteristics. The stage of plant growth is also a factor in estimating ET. Main environmental factors influencing ET are soil moisture, soil fertility, soil permeability, pests, and diseases.

Several ways of measuring the consumptive use of a plant directly are by using tank lysimeters, measuring water balance, measuring energy balance, and by determining mass transfer. Because these scientific methods are time consuming and costly, an estimated value is usually computed by using empirical methods. There are several classifications of these empirical methods that can be used for estimating plant consumptive use. These are based on estimates of climatic factors such as solar radiation, air temperature, pan evaporation, or a combination of these factors that are developed for various methods. The method that was chosen for use in the natural flow study was the SCS Blaney-Criddle method (Jensen, 1990), which is base on tempature. This method was chosen because it easily accommodates a monthly time step model and because of the data available for use in this model are given as a monthly time series.

Because Blaney-Criddle model is a temperature model, its main driving variables are temperature and precipitation. Other models such as the Penman, FAO-Penman, and Penman Monteith methods are much more accurate in estimating ET (Jensen, 1990), but the limited amount of climatic data available for the study did not allow for the use of these ET estimation methods. The temperature and precipitation data available from 1948 – 2002 were fairly complete for many stations scattered through out the study area. Only a few years of the weather records had to be reconstructed using statistical methods.

The ET computer model used by the Bureau of Reclamation for monthly planning studies is XCONSVB. (XCONSVB 1996) This program was developed in the late 1970's using FORTRAN and utilized the SCS Modified Blaney Criddle ET equation. Later updates include converting the FORTRAN code module to run with Visual Basic. This upgrade gives the user a graphical interface for ease of use and output organization. The input and output files are a text format file. The output of the model gives ET as a time series in inches per month.

Data –

Weather data was obtained from the National Weather Service via the internet at the Western Region Climate Center (http://www.wrcc.dri.edu/climsum.html) and through various CD data bases produced by HydroSphere in Boulder, Colorado. (Hydrosphere 2002) The following meteorological stations were used to compile the needed average temperature and monthly precipitation data for this study: Rocky Point 3S, Fort Klamath 7SW, Chiloquin 7NW, Chiloquin 1E, Klamath Falls 2SSW, Merrill 2N, Sprague River 2 SE, Tulelake CA, Chemult, and Round Grove.

With the XCONSVB model there are several other parameters that must be determined in order to complete the ET portion of the mass balance and these are cropping type and the amount of acres each crop or plant type encompasses. The cropping type can usually be found through statistical publications such as the USDA National Agricultural Statistics Service's County Ag Statistics (http://www.nass.usda.gov/census/) or by field verification. The amount of acreage covered by a certain plant type is more easily determined through remote sensing and satellite imagery. Several sources of data were used in this study to determine land use and total acreage of plant and crop type. GIS coverages composed by Oregon Water Resources Department for use in water right data bases and hydrology studies were provided for the Upper Klamath Basin tributaries (LaMarche, electronic communication, 2003). LandSAT satellite imagery was also available for most all the area in the Upper and Lower Klamath Basins.

The growing season of the crops and wetlands are another parameter that was determined and input into the model. Since there was ample data provided by Oregon State University on the crop-growing season for the area, this was a relatively easy parameter to determine (Cuenca, 1999). The wetland-growing season was more difficult to determine so an estimated growing season based on information from Ron Hathaway and Rod Todd of Oregon State University, Cooperative Extension Service and knowledge of the area was used for input into the XCONSVB model.

Crop coefficients used by the XCONSVB program were developed from the SCS Technical Release 21 (SCS 1970) for all crops in the area. The wetland and riparian crop coefficients were developed from a Salinity Investigation of the Price-San Rafael Rivers Unit performed by CH2M Hill (CH2M HILL 1983) for the Bureau of Reclamation. [See Appendix X for these crop curves and coefficients.]

Procedure –

Step 1: The cropping pattern was established based on historical records and/or field investigations conducted in the study area. Multiple-cropped acreage, i.e., acreage on which two or more crops are produced in the same year, must also be identified. Further, of importance to this study is the determination of the acreages of wetland and riparian vegetation occurring within the study area.

Step 2: The weather station and the period of record for weather data used in the determination of crop water requirements is selected on the basis of data that is available and most appropriate for the study area.

Step 3: The growing or irrigation season for each crop is defined by the earliest and latest moisture use dates. For annual crops such as corn and spring small grains, the earliest moisture use date is normally assumed to be the planting date and the latest moisture use date as the day before harvest begins.

Step 4: The consumptive use of water by each crop in the cropping pattern is computed.

Step 5: Effective precipitation for each individual crop is computed.

Step 6: The net consumptive use (Net ET) for each crop in the cropping pattern is computed by subtracting the effective precipitation from the consumptive use.

Step 7: The crop distribution ratio is computed by dividing the area planted in each individual crop by the total area for all crops included in the cropping pattern.

Step 8: Multiplying the Net ET by the crop distribution ratio yields the weighted Net ET for a plant or crop type. The sum of all the weighted Net ETs is the ET for the cropping pattern. If the cropping pattern includes multiple-cropped acreage, i.e., acreage on which two or more crops are produced in the same year, the Net ET for the cropping pattern is multiplied by the ratio of the gross irrigated acreage to the net irrigated acreage to yield the adjusted Net ET for the cropping pattern. The net irrigated acreage is the difference between the gross irrigated acreage and the multiple-cropped acreage.

- *Plant and Cropping Patterns*

Three different cropping or plant type patterns were used in this analysis. The first was an actual cropping pattern based on data compiled from field investigations and land use coverages of the area. This pattern consisted mostly of grass pasture with some alfalfa. The second pattern was a wetland plant mix consisting of salt grass, rushes, sedges, tules, and cattails. The final plant grouping was for the riparian fringes of the rivers and streams or a phreatophyte mixture of willows and cottonwood trees. Each plant was given an equal distribution in order to achieve an average evapotranspiration value for the riparian areas.

- *Growing or Irrigation Seasons*

The growing or irrigation season for each of the annual and perennial crops in the Upper and Lower Klamath Lakes and basin area used in the consumptive irrigation requirement analysis is as follows:

Alfalfa: The irrigation season for this perennial crop is defined by threshold temperatures, i.e., growth begins when the mean daily air temperature reaches 50° F in the spring, and it ends the day after the mean daily air temperature of 45° F or below occurs in the fall for the Upper Klamath and Lower Klamath Lake areas. The Williamson and Sprague river valleys used a threshold temperature of 47° F in the spring and 45° F in the fall or after the first frost period. On the basis of this criterion, the irrigation season is approximately April 15 – May 1 through October 15 - 30.

Pasture (Native and Improved): The irrigation season for this perennial crop is defined by threshold temperatures, i.e., growth begins when the mean daily air temperature reaches 45° F in the spring, and it ends when the mean daily air temperature falls below 45° F in the fall. On the basis of these criteria, the irrigation season is approximately April 15 through October 15.

Northern Climate Pasture: The growing season for this perennial crop is defined by threshold temperatures, i.e., growth begins when the mean daily air temperature reaches 45° F in the spring, and it ends when the mean daily air temperature falls below 45° F in the fall. On the basis of these criteria, the average growing season is approximately April 15 through October 15.

Spring Grain: Includes annual crops such as barley, oats, spring wheat, and other small grains which normally mature in 130 days or less. The irrigation season is defined as May 10 through September 15.

Sugar Beets: The irrigation season is defined as May 15 through October 15.

Potatoes: The irrigation season is defined as May 15 through October 15.

Northern Climate Salt Grass: The growing season for this perennial crop is defined by threshold temperatures, i.e., growth begins when the mean daily air temperature reaches 45° F in the spring, and it ends when the mean daily air temperature falls below 45° F in the fall. On the basis of these criteria, the irrigation season is approximately April 15 through October 15.

Cottonwoods 8ft root depth: The growing season for this perennial crop is defined by threshold temperatures, i.e., growth begins when the mean daily air temperature reaches 42° F in the spring, and it ends when the mean daily air temperature falls below 42° F in the fall. The typical average growing season for this plant is from April 10 through October 25.

Mature Willow Trees: The growing season for this perennial crop is defined by threshold temperatures, i.e., growth begins when the mean daily air temperature reaches 42° F in the spring, and it ends when the mean daily air temperature falls below 42° F in the fall. The typical average growing season for this plant is from April 10 through October 25.

Rushes and Sedges: The growing season for this perennial plant mix was defined by threshold temperatures, i.e., growth begins when the mean daily air temperature reaches 45° F in the spring, and it ends when the mean daily air temperature falls below 45° F in the fall. The typical average growing season for this plant is from April 20 through October 15.

Tules and Cattails: The growing season for this perennial plant mix was defined by threshold temperatures, i.e., growth begins when the mean daily air temperature reaches 45° F in the spring, and it ends when the mean daily air temperature falls below 45° F in the fall. The typical average growing season for this plant is from April 15 through October 15.

Consumptive Use (CU) or Evapotranspiration (ETc) Computed using the SCS Modified Blaney-Criddle Method –

The U.S. Soil Conservation Service modified Blaney-Criddle method was introduced in 1967 and later revised and published in 1970 (SCS 1970). The method uses mean monthly air temperatures (T) expressed in degrees Fahrenheit, monthly percentage of annual daylight hours (P) based on the latitude of the area under study, monthly consumptive use coefficients (k), and length of growing season to estimate the total consumptive use (CU) of water or evapotranspiration (ETc) during the growing season for a crop that is well-watered and free of disease. The consumptive use in inches for each month is expressed as:

$$CU = ETc = [(T)(P)/100](k)$$

Where $k = (k_t)(k_c)$ and $k_t = 0.0173*T\text{-}0.314$

The distinctive feature of the SCS modified Blaney-Criddle method is the procedure used to arrive at the final value of the consumptive use coefficient (k). First, the climatic coefficient (k_t), which is expressed as a function of the mean monthly temperature, is computed. Then the value of the crop growth stage coefficient (k_c) is obtained from a curve plotted on a graph or tabulation. Because the growth characteristics of each crop are different, a separate curve is generally required for each crop. Curves for a limited number of crops were published in SCS Technical Release 21 (1970). Multiplying k_c by k_t yields the final value of the consumptive use coefficient (k) for a specific crop and month. In a month in which the growing season begins or ends, the consumptive use coefficient is multiplied by the ratio of the number of days in the month the crop is "growing" to the total number of days in that month.

- *Effective precipitation (EP) computed using the SCS method*

Results of research which evaluated the soil-moisture balance derived from analysis of 50 years of precipitation records at each of 22 Weather Bureau stations in the United States, the Soil Conservation Service developed a method for estimating effective rainfall which is a function of the plant consumptive use and rainfall. The effective precipitation (EP) in inches is expressed as:

$$EP = (0.70917*R_t^{0.82416} - 0.11556)*10^{0.0242} * u(f)$$

where R_t is the precipitation in inches; CU is the monthly consumptive use in inches; and f is given as:

$$f = 0.531747 + 0.295164*D - 0.057697*D^2 + 0.003804*D^3$$

where D is the net depth of irrigation water in inches which is normally applied to the field. Note that the effective precipitation (EP) cannot exceed the average monthly rainfall or average monthly consumptive use (CU or ET_c). The monthly consumptive irrigation requirement for each crop in the cropping pattern is computed by subtracting the effective precipitation (EP) from the consumptive use (CU or ET_c).

Summing the effective rainfall computed for each month yields the total effective rainfall for a specific crop during the growing season.

- *Potential Net ET*

The monthly consumptive irrigation requirement for each crop in the cropping pattern is computed by subtracting the effective precipitation (EP) from the consumptive use (CU or ET_c). This calculation is expressed as:

$$\text{Net } ET = CU - EP = ET_c - EP$$

The total or seasonal consumptive irrigation requirement for a specific crop is sum of the monthly consumptive irrigation requirements.

River/Lake Basin Computations and Analysis –

- *Upper Klamath Lake River Basins*

From the collection of the data and the general topography and land it was determined that the two tributaries to the Williamson River, Sprague River and Sycan River, as well as the Wood River would be treated as separate basins for the flow computations. Land use classification of the watersheds was completed and ET estimation was calculated for each basin. A GIS map of the region (Fig. A) shows the major land classes and basins divisions that were used to calculated the ET for the 4 major river basins.

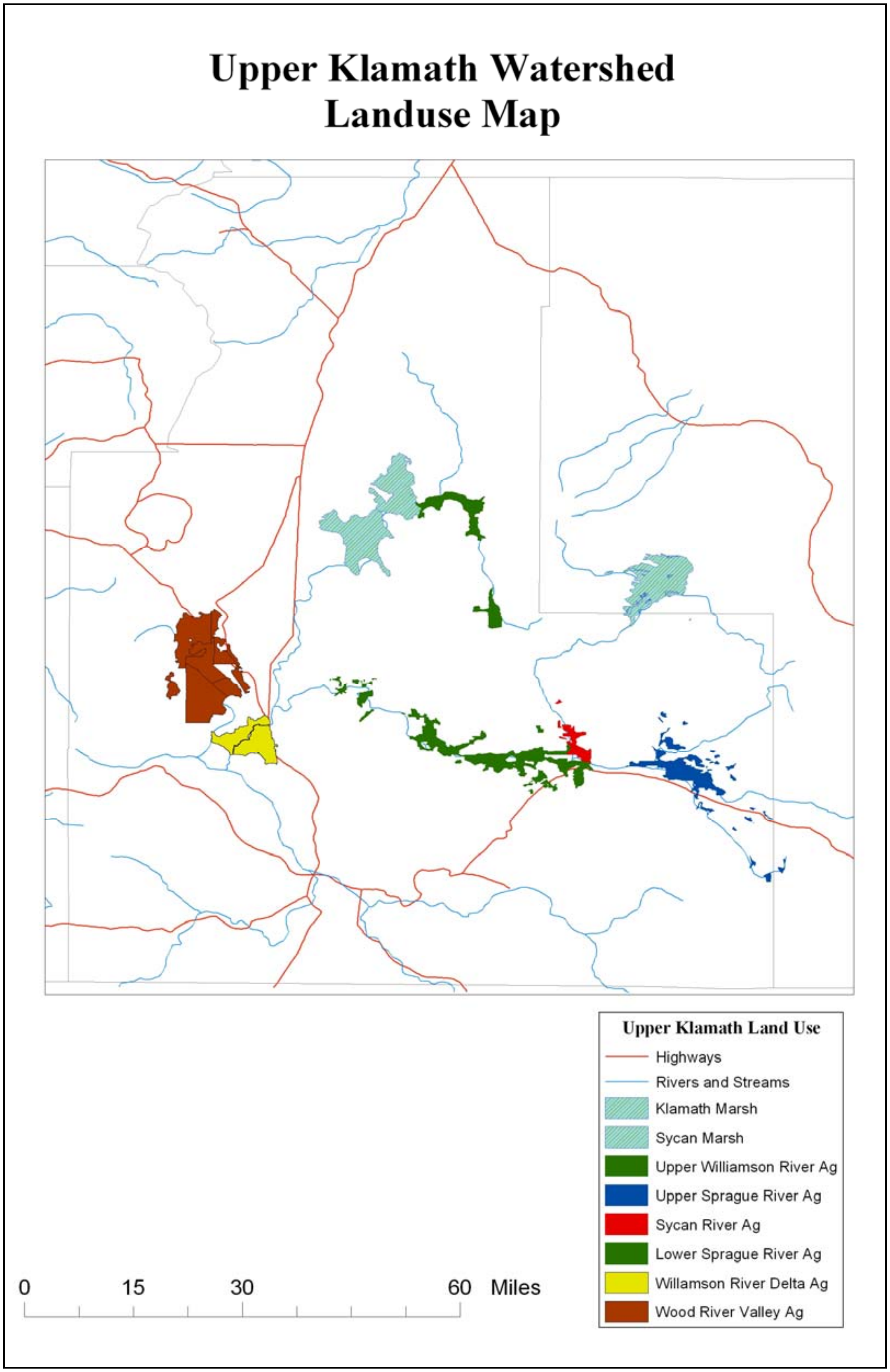

Figure A. GIS coverage map of the Upper Klamath Lake watershed land use and land class.

The Sprague River Valley was divided into an upper and lower reach for further simplifications of the calculations. The upper basin contained 17,132 acres of agricultural lands (primarily grass and alfalfa) and 8,224 acres of marsh lands (primarily salt grass with some tules and rushes). The lower basin was comprised of 30,851 acre of agricultural lands. The marsh lands were drained and converted to agricultural uses and no historical record existed of the historical natural vegetation on this reach. The three climatic stations that were used in the ET computation were Sprague River 2SE, Chiloquin 1E, and Round Grove.

The Sycan River is the major tributary to the Sprague River. It contains an estimated 4,806 acres of agricultural lands and 15,311 acres of riparian and marsh lands. In addition to the agricultural and riparian areas was the Sycan Marsh at the head waters of the Sprague River. The Sycan March encompasses approximately 22,627 acres of land. The Sprague River 2SE climatic station was used for the Sycan River ET calculations.

The Main Williamson River basin contains 12,793 acres of irrigated pasture and 37,844 acres of marsh land. An estimated 48,474 acres of historic marsh land occurred prior to reclamation of the land for agricultural and development purposes within this watershed. There is a small diversion on the lower reaches of the river that services 6,000 acres of agricultural crops. The crop type mix was determined to be alfalfa, potatoes, sugar beets, grain, and pasture for the purposes of a separate water balance for that system. The Chemult and Chiloquin 1E gages were used for climatic data.

The last river basin in the system that was considered for the ET calculations was the Wood River. This valley is comprised of 30,000 acres of primarily irrigated pasture grasses. There are some riparian areas along the river and agricultural drainage ways that will be considered in the Upper Klamath Lake ET discussion.

- *Upper Klamath Lake ET*

The Upper Klamath Lake (UKL) marshland and riparian areas were handled differently than the previous basin calculations in regards to ET. Reconstructed precipitation histories were used for three incomplete climatic stations in the area. These stations were Chiloquin 7 NW near the fish hatchery, Fort Klamath 7SW near Cherry Creek and Rocky Point 3 S near Pelican Bay on the UKL. Two meteorological stations with complete history were also utilized, Chiloquin 1 E and Klamath Falls 2SSW. The ET was estimated using the Modified Blaney Criddle method as described previously. Also provided were planimetered acreage values of the marshland and riparian areas in and around UKL.

Three vegetation classifications were determined: Lake Wetland Marsh, Emergent Lake Marsh, and Riparian Marsh. The Lake Wetland type consisted of vegetation that was completely submerged year round, such as bulrush, sedges, cattails, and tules. The Emergent Lake Marsh type represents vegetation that is submerged only partially during the growing season such as salt grasses. The Riparian areas consisted of a mix of rushes and tules as well as willow and cottonwood trees. For this exercise an 80% rushes and 20% willow plant mix was used. The total acreages for the marsh area were then divided between the 5 meteorological stations in the area. The HUC number is the USGS delineation of river basins into sub-basins for accounting purposes. Table 1 provides a disaggregating of the various marsh land type acreages and respective climate stations. The total net consumptive use for these areas was then calculated using the XCONSVB model.

Upper Klamath Lake Marsh Land Acreages				
Station	**HUC**	**Lake Wetland Marsh**	**Emergent Lake Marsh**	**Riparian Marsh**
Chiloquin 1E	18010202	10,061	0	0
Chiloquin 7NW	18010201	5,632	1,350	877
Fort Klamath 7SW	18010203	9,251	7,616	109
Klamath Falls 2SSW	180102104	11,034	192	0
Rocky Point 3S	18010203	17,328	467	0

Table 1. Marsh acreages for the Upper Klamath Lake area.

- *Lower Klamath Lake and Marsh Area*

ET computations for Lower Klamath Lake (LKL) and Marsh areas were developed much the same as those for the UKL areas. The planimetered acreage of the historical marsh area was divided between two climatic stations. The Klamath Falls 2SSW and Merrill 2N data stations were used. Total marsh area was 55,842 acres with 37,208 acres in the Klamath Falls station area and 18,634 acres in the Merrill station area. Modified Blaney Criddle was used to estimate consumptive use. Bulrush, sedges, cattails, and tules were used as the plant type for the consumptive use curves.

- *Results*

The output from XCONS is given in total inches per month and an annual total consumptive use in inches. The output gives total consumptive use, effective precipitation and net consumptive use, which is a difference in the total and the effective precipitation. The output was then imported into an Excel spreadsheet for ease of manipulation of the data. The data was separated by major land use type, Agricultural, Marshland, and Riparian areas. The net ET was then multiplied by the respective acreage of each land type and converted to acre-feet for the final output table. See table 1 for an example of the final output for Sycan River Agricultural lands.

Net Consumptive Use in Acre-Feet
Total Acreage in Sycan 4806 Acres
Values in Acre-Feet
Climate Station Use: Sprague River

Station	State	Crop	Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Sprague River	Oregon	Crop Mix	1948	0	0	0	0	396.50	1,551.27	1,365.71	1,188.15	1,031.96	70.76	0	0	5,604.33
Sprague River	Oregon	Crop Mix	1949	0	0	0	48.06	1,013.27	1,380.39	2,061.24	1,632.71	1,364.37	182.90	0	0	7,678.92
Sprague River	Oregon	Crop Mix	1950	0	0	0	0	508.64	1,289.61	2,079.93	2,017.19	0	162.87	0	0	6,059.57
Sprague River	Oregon	Crop Mix	1951	0	0	0	60.08	1,064.00	1,763.54	2,101.29	1,668.75	651.48	21.36	0	0	7,329.15
Sprague River	Oregon	Crop Mix	1952	0	0	0	154.86	488.61	1,206.84	2,172.05	1,527.24	1,233.54	443.22	0	0	7,225.02
Sprague River	Oregon	Crop Mix	1953	0	0	0	0	686.19	1,126.74	1,832.96	1,520.57	949.19	0	0	0	6,112.97
Sprague River	Oregon	Crop Mix	1954	0	0	0	254.99	720.90	1,246.89	1,943.76	1,355.03	853.07	33.38	0	0	6,409.34
Sprague River	Oregon	Crop Mix	1955	0	0	0	-	598.08	1,540.59	1,728.83	1,638.05	806.34	9.35	0	0	6,321.23
Sprague River	Oregon	Crop Mix	1956	0	0	0	85.44	682.19	947.85	2,148.02	1,561.95	467.25	277.68	0	0	6,173.04
Sprague River	Oregon	Crop Mix	1957	0	0	0	172.22	1,062.66	2,058.57	2,304.21	1,168.13	608.76	28.04	0	0	7,403.91
Sprague River	Oregon	Crop Mix	1958	0	0	0	66.75	516.65	1,282.94	2,097.29	1,830.29	914.48	499.29	0	0	7,209.00
Sprague River	Oregon	Crop Mix	1959	0	0	0	0	415.19	1,573.97	1,791.57	1,349.69	818.36	393.83	0	0	6,342.59
Sprague River	Oregon	Crop Mix	1960	0	0	0	0	658.16	1,585.98	2,293.53	1,455.15	955.86	0	0	0	6,950.01
Sprague River	Oregon	Crop Mix	1961	0	0	0	0	528.66	1,926.41	1,895.70	1,836.96	509.97	61.41	0	0	6,760.44
Sprague River	Oregon	Crop Mix	1962	0	0	0	0	456.57	1,464.50	1,607.34	1,250.90	0	164.21	0	0	4,943.51
Sprague River	Oregon	Crop Mix	1963	0	0	0	0	946.52	1,264.25	1,351.02	1,610.01	1,027.95	0	0	0	6,202.41
Sprague River	Oregon	Crop Mix	1964	0	0	0	0	188.24	1,161.45	2,053.23	1,623.36	938.51	80.10	0	0	6,046.22
Sprague River	Oregon	Crop Mix	1965	0	0	0	316.40	461.91	1,504.55	1,193.49	1,656.74	926.49	0	0	0	6,058.23
Sprague River	Oregon	Crop Mix	1966	0	0	0	184.23	937.17	958.53	1,376.39	1,612.68	1,109.39	0	0	0	6,177.05
Sprague River	Oregon	Crop Mix	1967	0	0	0	0	803.67	1,684.77	2,329.58	2,152.02	855.74	351.11	0	0	8,172.87
Sprague River	Oregon	Crop Mix	1968	0	0	0	0	861.08	1,623.36	1,727.49	1,623.36	505.97	62.75	0	0	6,404.00
Sprague River	Oregon	Crop Mix	1969	0	0	0	162.87	632.79	1,782.23	2,114.64	1,664.75	889.11	101.46	0	0	7,347.84
Sprague River	Oregon	Crop Mix	1970	0	0	0	0	957.20	1,903.71	2,253.48	1,843.64	387.15	0	0	0	7,343.84
Sprague River	Oregon	Crop Mix	1971	0	0	0	9.35	715.56	1,419.11	2,212.10	1,818.27	776.97	32.04	0	0	6,980.72
Sprague River	Oregon	Crop Mix	1972	0	0	0	0	853.07	1,770.21	2,107.97	1,695.45	469.92	186.90	0	0	7,084.85
Sprague River	Oregon	Crop Mix	1973	0	0	0	156.20	1,373.72	1,770.21	2,038.55	1,564.62	492.62	0	0	0	7,397.24
Sprague River	Oregon	Crop Mix	1974	0	0	0	0	723.57	1,873.01	1,890.36	1,899.71	1,170.80	196.25	0	0	7,753.68
Sprague River	Oregon	Crop Mix	1975	0	0	0	0	672.84	1,076.01	1,998.50	1,608.68	640.80	142.85	0	0	6,137.00
Sprague River	Oregon	Crop Mix	1976	0	0	0	25.37	1,066.67	1,092.03	1,393.74	1,435.13	1,249.56	399.17	0	0	6,662.99
Sprague River	Oregon	Crop Mix	1977	0	0	0	0	383.15	1,986.48	2,105.30	1,411.10	907.80	10.68	0	0	6,801.83
Sprague River	Oregon	Crop Mix	1978	0	0	0	0	479.27	1,441.80	1,922.40	1,469.84	977.22	347.10	0	0	6,636.29
Sprague River	Oregon	Crop Mix	1979	0	0	0	64.08	1,073.34	1,620.69	1,455.15	1,716.81	345.77	134.84	0	0	6,410.67
Sprague River	Oregon	Crop Mix	1980	0	0	0	150.86	631.46	1,145.43	2,188.07	1,520.57	857.07	256.32	0	0	6,749.76
Sprague River	Oregon	Crop Mix	1981	0	0	0	68.09	913.14	1,559.28	2,022.53	1,882.35	752.94	0	0	0	7,196.99
Sprague River	Oregon	Crop Mix	1982	0	0	0	0	603.42	1,525.91	1,982.48	1,560.62	588.74	48.06	0	0	6,306.54
Sprague River	Oregon	Crop Mix	1983	0	0	0	16.02	967.88	1,280.27	1,568.63	1,899.71	776.97	0	0	0	6,508.13
Sprague River	Oregon	Crop Mix	1984	0	0	0	0	736.92	1,451.15	1,620.69	1,806.26	560.70	0	0	0	6,177.05
Sprague River	Oregon	Crop Mix	1985	0	0	0	148.19	973.22	1,416.44	2,213.43	1,078.68	751.61	104.13	0	0	6,687.02
Sprague River	Oregon	Crop Mix	1986	0	0	0	0	991.91	2,105.30	1,922.40	1,589.99	648.81	236.30	0	0	7,493.36
Sprague River	Oregon	Crop Mix	1987	0	0	0	423.20	877.10	1,509.89	1,831.62	1,800.92	1,233.54	587.40	0	0	8,263.65
Sprague River	Oregon	Crop Mix	1988	0	0	0	132.17	683.52	1,656.74	2,277.51	1,716.81	1,110.72	0	0	0	7,576.13
Sprague River	Oregon	Crop Mix	1989	0	0	0	401.84	1,023.95	1,698.12	1,752.86	1,140.09	548.69	218.94	0	0	6,787.14
Sprague River	Oregon	Crop Mix	1990	0	0	0	86.78	722.24	1,224.20	1,885.02	1,549.94	1,126.74	347.10	0	0	6,946.01
Sprague River	Oregon	Crop Mix	1991	0	0	0	0	536.67	1,230.87	2,356.28	2,031.87	1,220.19	299.04	0	0	7,674.92
Sprague River	Oregon	Crop Mix	1992	0	0	0	308.39	1,137.42	1,734.17	2,050.56	1,943.76	451.23	263.00	0	0	7,885.85
Sprague River	Oregon	Crop Mix	1993	0	0	0	1.34	951.86	1,325.66	1,297.62	1,451.15	861.08	295.04	0	0	6,185.06
Sprague River	Oregon	Crop Mix	1994	0	0	0	156.20	1,054.65	1,094.70	2,228.12	1,623.36	1,141.43	10.68	0	0	7,309.13
Sprague River	Oregon	Crop Mix	1995	0	0	0	102.80	558.03	1,106.72	1,764.87	1,436.46	1,082.69	89.45	0	0	6,141.00
Sprague River	Oregon	Crop Mix	1996	0	0	0	0	479.27	1,419.11	2,117.31	1,476.51	690.20	10.68	0	0	6,190.40
Sprague River	Oregon	Crop Mix	1997	0	0	0	29.37	1,007.93	939.84	1,636.71	1,352.36	743.60	21.36	0	0	5,731.16
Sprague River	Oregon	Crop Mix	1998	0	0	0	0	283.02	1,108.05	2,132.00	1,557.95	1,043.97	0	0	0	6,124.98
Sprague River	Oregon	Crop Mix	1999	0	0	0	0	562.04	1,316.31	1,379.06	1,738.17	784.98	332.42	0	0	6,114.30
Sprague River	Oregon	Crop Mix	2000	0	0	0	472.59	1,189.49	1,703.46	2,293.53	1,771.55	760.95	196.25	0	0	8,389.14
Sprague River	Oregon	Crop Mix	2001	0	0	0	52.07	1,214.85	1,221.53	1,975.80	1,724.82	1,125.41	0	0	0	7,314.47

<u>Table 2</u>. Example output of ET data used in flow reconstruction process.

After computing the net ET for several of the climatic stations, plots were created to observe the plant water use curve to verify the accuracy of the established crop curve. Several stations were not climatically representative for the specific river basin and had to be discarded or used to calibrate and reconstruct other climatic stations. The plot shown in Figure B is an example of the crop curves that were created.

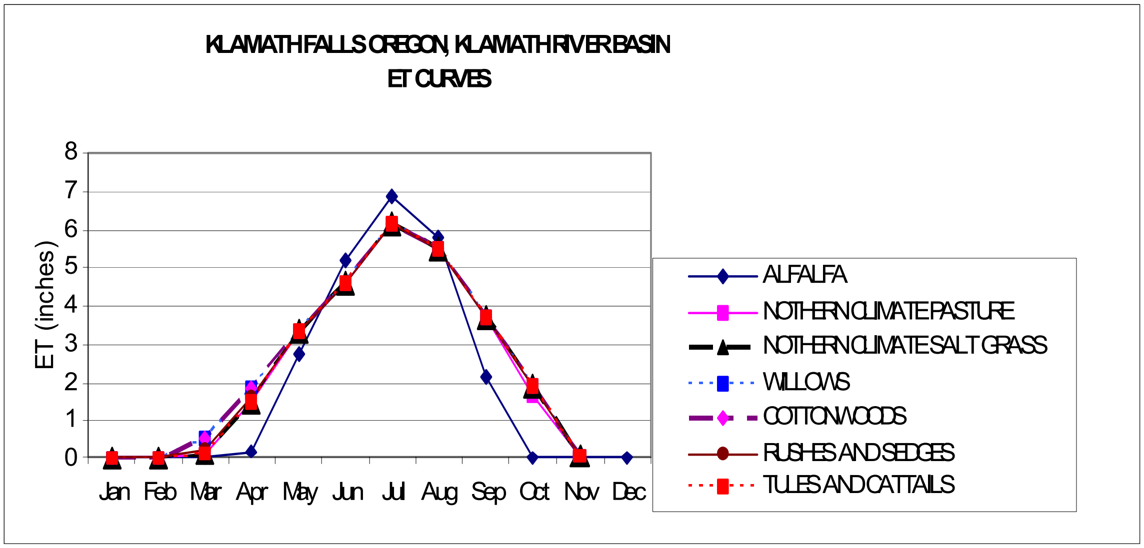

Figure B. Plot of various crops ET curves for the Klamath Falls 7SSW station.

- *Discussion*

The results of the ET calculations were compared against the Oregon Crop Water Use and Irrigation Requirements guide for validation (Cuenca 1999). This guide was the best source for comparing measured crop ET values to the XCONS model estimations. The estimates were then adjusted by increasing or decreasing the growing season length for best estimation.

According to the Oregon Crop Water Use Guide (Cuenca 1999) the average year ET for alfalfa hay in the Klamath Falls region is 1.6 feet, Grain is 1.8 feet, and for pasture it is 2.6 feet. The average annual ET values calculated from XCONSVB for alfalfa, grain, and pasture all fall within 10% of the values estimated in the Oregon Crop Water Use Guide. See Table 3 for actual average annual ET values from XCONSVB and the Oregon Crop Water Guide.

Analysis of Crop ET values **Average year ET estimation calculations**		
	XCONSVB	**Oregon Crop Water Guige**
Alfalfa	1.7	1.6
Irrigated Pasture	1.8	2.6
Grain	1.2	1.8
ET Values in feet		

Table 3. Annual estimated ET values for various crops in the Upper Klamath River Basin.

A panel of hydrologists, agronomists, agricultural engineers, and scientists for the Klamath Watershed Conference 2004 all agreed on the following ranges of open water evaporation and ET for the Upper Klamath Basin: The open water evaporation from April – October ranges from 2.7 – 3.3 feet on Upper Klamath Lake; the ET for emergent marshland on Upper Klamath Lake from April – October ranged from 2.2 – 2.7 feet; and irrigated pasture in the

Upper Klamath Basin April -- October ranged from 2 – 2.4 feet. All these values have an annual range of .5 feet due to climate variations, soil types, and available soil moisture variations. The confidence in the values that were produced for this study is in the order of 80% due to the errors in the SCS Blaney Criddle Method as well as rounding errors generated by the XCONSVB program.

There has been much discussion about the annual ET or consumptive use of wetland marshes. The best available data that is site specific and relatively usable for the Upper Klamath Basin is the work done by William Bidlake of the US Geological Survey (USGS 2000). His study was performed on three marsh sites at the Klamath Forest and Lower Klamath National Wildlife Refuges in south-central Oregon and northern California. The study was prepared for the US Fish and Wildlife Service (FWS). The results of his study were a total ET for the six month period of May 1 to October 31, 1996 were 2.2 – 2.7 feet of water. Other studies by the USGS for FWS include the Ruby Lake National Wildlife Refuge in northeastern Nevada. ET estimates for May 1 - October 31 over a two year study that spanned May 1999 – October 2000 resulted in open water evaporation of approximately 3.3 feet. A bulrush marsh evaporated 1.1 feet in the winter to 3.1 feet from May 1 - October 31. This area is comparable in latitude, average air temperature, and relative humidity to Klamath Falls Oregon. The only real factor that makes this study differ from Bidlake's in Klamath is the elevation difference (6000 feet at Ruby Lake vs. 4100 feet at UKL).

The variation of estimated wetland ET values from XCONSVB in this study is from 1.25 – 2 feet in the Klamath Marsh from May 1 through October 15. In the Wood River Valley or Upper Klamath Lake area the wetlands consumed on the order of 1.6 – 2.6 feet of ET for the May 1– October 31. The Lower Klamath Lake marsh lands in approximately the same time period used 1.25 – 1.7 feet. Thus, comparing these estimated values to Bidlake's measured values, the range seems to cover the actual measured marshland ET in the UKL. This underestimate will account for the drying of some of the upland marsh areas in dry years while covering the best estimated ET for wetter than average years.

Results from the two USGS studies and estimates used by Oregon Water Resources Department in their studies are shown in Table 4 and visually compared in Figure C to show how those results compare with the XCONSVB estimates used by USBR in this study.

Range of ET and Evaporation Values in the Upper and Lower Klamath Basin
Upper Klamath Basin, April - October Season Value (feet)

	Open Water Evaportation		Marsh land ET		Irrigated Pasture ET	
	Max	Min	Max	Min	Max	Min
Oregon Water Resources Department (La Marche, 2004)	3.3	2.7	2.7	2.2	2.4	2.1
US Bureau of Reclamation (XCONSVB)	3	2.4	2.3	1.3	2	1.2
US Geological Survey (Bidlake & Berger, et. al.)	3.3	2.2	2.7	2.2		

Table 4. ET and open water evaporation comparisons between USGS, USBR, and OWRD studies results.

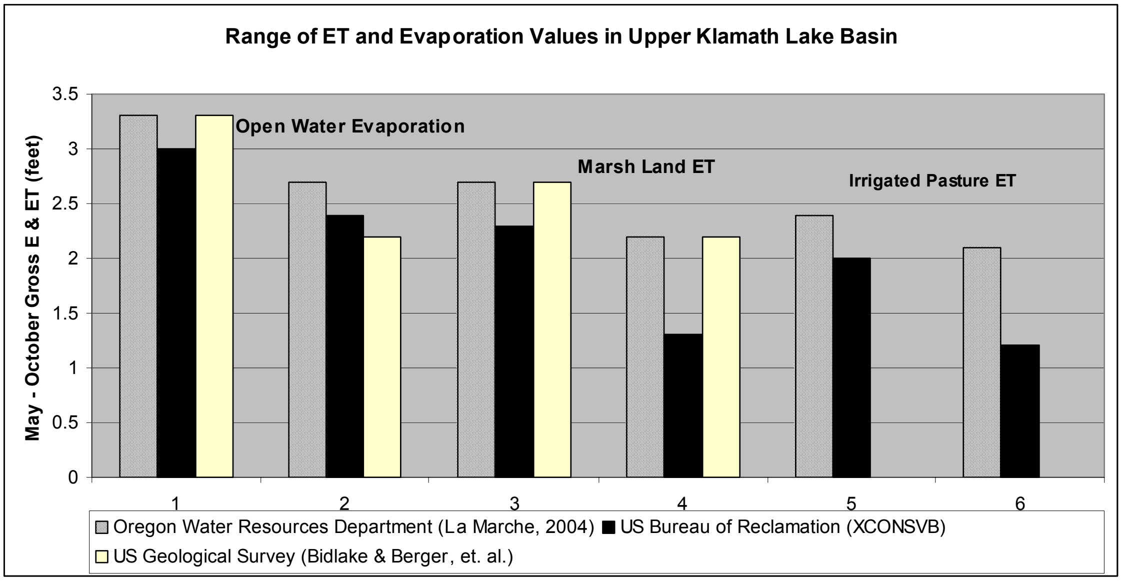

Figure C. Graphical presentation of comparison between OWRD, USGS, and USBR.

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Appendix 1-2X: Calculation of open-water surface evaporation

No water balance calculation is complete without estimates or measurements of evaporative losses from the system in question. Unfortunately, there are few reservoir systems for which long-term evaporation measurements are available (Linsley, et al, 1982), particularly when considering pre-development conditions. Given these constraints, an empirical or energy balance method of estimating evapotranspiration in the Klamath system must be developed.

Energy balance method –

The Penman Equation is one of the most widely used and accepted methods for calculating potential evaporative losses from a free water surface. Penman is also considered by many to be the recommended method when appropriate data are available (FutureWater, 2003, Snyder, 2000). Estimations of potential evaporation are calculated by consideration of the requirements to balance the energy budget at the water surface (Penmanetc, 2003).

The Penman Equation requires a large amount of measured data, including net radiation exchange at the water surface, energy advected to the water body, minimum and maximum temperature, relative humidity, and wind speed (Penmanetc, 2003). Needless to say, the required data for proper calculation of Penman evaporation is not readily available in the Klamath basin, nor is it available for the period of record of this study.

The Bureau of Reclamation has recently begun collecting the necessary data to calculated a Penman derivative, the Kimberly-Penman, through the AgriMet station in Klamath Falls. These data are available for the period of March 31, 1999 through the present (AgriMet, 2003).

Empirical method –

The Hargreaves' Equation is an empirical formula derived to allow the estimation of potential evaporation based solely on air temperature, and knowledge of the latitude of the site (Penmanetc, 2003, Snyder, 2000). Even though the Hargreaves' Equation was originally developed to estimate evaporation from agricultural systems, reasonable estimates of potential evaporative losses can be obtained by considering monthly totals (Penmanetc, 2003).

Procedure that was used in this study to calculate potential evaporation –

The first attempt to determine potential evaporation was a correlation of existing Kimberly-Penman evaporation from the AgriMet station to readily available maximum, minimum, and average air temperature readings for the same period. This exercise resulted in only marginal success with R^2 values ranging from 0.61 to 0.79.

Because of the lack of appropriate data necessary to calculate evaporation using the Penman Equation, and the references obtained indicating that the Hargreaves' Equation is capable of producing reasonable results (Penmanetc, 2003, Hargreaves', 2003, FutureWater, 2003), the Hargreaves' Equation was chosen for this study.

The Hargreaves' Equation takes the form:

$$E = 0.0023 S_0 (T + 17.8)\sqrt{\delta}$$

Where:

E = Potential evaporation (mm/day)
T = Temperature (°C)
δ_T = The difference between mean monthly maximum and minimum temperatures (°C)
S_0 = Extraterrestrial radiation given by:

$$S_0 = 15.392 d_r (\omega \sin \phi \sin \gamma + \cos \phi \cos \gamma \sin \omega)$$

Where:

ϕ = Site latitude
ω_s = Sunset hour angle (radians) given by:

$$\omega = \arccos(-\tan \phi \tan \gamma)$$

γ = Solar declination on julian day J given by:

$$\gamma = 0.4093 \sin\left(\frac{2\pi}{365} J - 1.405\right)$$

d_r = Relative distance from the earth to the sun for julian day J given by:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right)$$

The temperature and station location data used to calculate the Hargreaves' potential evaporation came from the 2002 Hydrodata CD.

Evaporation for six stations: Klamath Falls, Chemult, Chiloquin, Merrill, Sprague River, and Tule Lake, was calculated. Two stations were used to get a complete period of record for the Klamath Falls area, with the primary data coming from the 2SSW station. Missing data was supplemented from the Ag. station when available.

The daily Hargreaves' evaporation estimates were compared with the Kimberly-Penman evaporation data obtained for the Bureau of Reclamation AgriMet station for the period March 31, 1999 through December 1, 2001. The data were correlated with an r^2 of 0.92. The Hargreaves' Equation generally gave a lower estimate than the Kimberly-Penman calculation. Based on the correlation of Hargreaves' and Kimberly-Penman evaporation calculations, an adjusted Hargreaves' estimate was also developed.

Appendix 1-3X: Time series synthesis and other statistical methods

Time series synthesis –

Restoration of gaged monthly flow histories to longer-term natural flow histories and the determination of inflows from ungaged watersheds must consider development of complete records for the period of interest based on recorded information that is available. Within the study area, gaging station and meteorological records must be examined to determine if these records are complete, and if there is sufficient information in records from nearby stations that may be useable for the restoration of records used in the assessment. Limited, incomplete records provide a time-series history that is only partially representative of conditions within the study area. Therefore, to assess natural flows and formulate considerations for an assessment of natural water bodies, a time-series history for each related representative record must be developed based on a reconstruction that is representative and that covers the period of interest. In other words, the reconstruction must be consistent with conditions existing within the vicinity of the station associated with the record being reconstructed.

These considerations are important for two reasons. Net consumptive uses determined for irrigated crops and natural marshlands require a complete meteorological history of monthly precipitation and average temperature for the period of interest. The natural inflow to the water body cannot be determined if streamflow cannot be restored to natural flow by adjustments due to these consumptive uses. Further, many of the natural flows have been determined at inflow locations to stream reaches that must be treated in a water-budget to evaluate the inflow from the stream reaching the water body. Therefore, incomplete records, whether for meteorologic stations or stream gaging stations, must be reconstructed to provide a continuous time-series of monthly values for the period of interest.

To begin the reconstruction process, all supporting stream-gaging records must be reconciled as natural flow records. Such records will show streamflow as equivalent gaged natural flow. This is essentially measured flow at the gage that is unaltered by upstream diversions, reservoir storage, or other uses and longer-term temporal changes in watershed conditions that may adversely affect natural streamflow. Some records are already in this condition. However, records having demonstrated affects from upstream uses were adjusted to remove the alterations to the gaged flow caused by such uses. In many cases, upstream uses are inconsequential to restoration and the gaged flow may be considered equivalent to natural flow. This restoration process is necessary to remove alterations masking natural climatic variability that would be evident in these principally supporting stream-gaging records. Records possessing clear and essentially unmasked natural variations are generally easy to compare and cross-correlate, especially when such records may be of insufficient length to otherwise provide meaningful results, and must therefore be statistically restored to a longer period of record. Such records are also required to evaluate the impact of the alterations, especially in natural flow assessments.

Meteorological records, however, have different requirements. A meteorological time series for a station at one location must be reconciled to a record for a station existing at that location. Because a particular data record may be for a station that has been relocated, usually to a nearby location less than three miles away, records must be examined to determine if the new record is continuous with the older record or if there is a break due to slightly different climatic conditions existing at the new location. Records that are useable show no breaks and are continuous. Records that do not meet these criteria must be reconstructed because some of the data for one or more of the previous locations will not be useable.

In the correlation process, two types of records are considered. Primary records are time-series histories that are considered independent in forming the basis of the correlation. Such records are not considered the subject of the reconstruction, but are used in forming the basis for the reconstruction. Time-series histories that form the subject of the analysis, but are of insufficient length or have missing values, are considered as secondary records and must therefore be restored. The common base-period for the reconstruction must be of sufficient length that meaningful results may be derived from analysis of the records. For a collection of shorter-term records being used in the correlation process, the length of this common base-period is usually defined as beginning with the date of the earliest record starting the period in question, and finishing with the ending date of the latest record terminating the period in question. A least-squares correlation procedure is used to derive the values that are absent within this established, inclusive, common base-period of record.

For this analysis to be successful, three criteria must generally be satisfied. Although previously stated somewhat differently, the basic premise of these criteria is still the same. First, the primary record used to restore missing values in a secondary record must have unaltered seasonal characteristics or monthly variation characteristics that are similar to the secondary record being restored. Unaltered seasonal characteristics, as indicated previously, are indicative of the regional climatic factors. Second, concurrence of these records must provide sufficient values to demonstrate meaningful results in the use of correlation analysis. If concurrence is insufficient, correlation results can become deceptive or difficult to interpret. Third, the primary records that are being used must be for stations in the geographic vicinity of the secondary records being restored. As indicated previously, this is necessary to maintain regional consistency in relation to climatic factors that affect precipitation and drive streamflow.

Correlation analysis is a statistical procedure by which values missing in a secondary record, **B**, may be estimated through correlation of this secondary record with a primary record, **A**. This method uses a least squares, or similar, procedure to fit a straight, or curved, line through the [x,y] scatter plot evidenced by corresponding **[A,B]** values within the two data sets. The primary data set, **A**, is taken as the independent (x-axis) variable while the secondary data set, **B**, is taken as the dependent (y-axis) variable. Evidence of a good correlation between corresponding values in **A** and **B** is indicated when the points that comprise the scatter plot may be closely approximated by, or lie close to, the line fitted to the scatter plot. For records that are time associated, missing values in **B** are then computed from the equation for the line by using the appropriate time associated value given in **A**. The explained variation in relating the secondary data set, **B**, with the variation in the primary data set, **A**, is usually very good when the correlation relationship is good. This means that the variability in **B**, for instance, or difference across the range from high to low values in **B**, is explained well when the correlation of **B** with **A** is good. Generally, however, when the correlation relationship declines, the explained variation declines. When there is no correlation between the data sets, the least-squares line of relationship between **A** and **B** has simply one value equal to the average noted for the data group in **B** forming the scatter plot with the concurrent data group in **A**. Therefore, as the explained variability declines, values missing in **B** that are reconstructed using a least-squares procedure, tend toward the average for the values originally existing in **B** that are, as a data group, concurrent with corresponding values in **A**. This loss of information regarding explained variability is particularly important in the assessment of extreme values, or those occurring at the high and low ends of the range in reconstructed data for **B**. Hence, with adequate data, the variation explained through the use of correlation analysis is directly related to demonstration of meaningful results in the analysis of the records.

Completion of the reconstruction process is relatively straightforward. A pool of available primary records is statistically compared in the correlation with the secondary record being reconstructed and the explained variation being recovered is noted in a matrix for each month with each primary record. This explained variation is used as a guide, but not as a rule, in selecting the best monthly correlations that will be assembled into the final record. Because this analysis was carried out on a calendar month basis, the best correlation for each given month could be chosen from the cadre of correlation results that were available from the pool of useable records. In addition, there are special considerations that must be examined in completing the correlation analysis. Real values that cannot be negative must be derived from a line forced through the origin. Where loss of information in the correlation is noted to significantly degrade recovered variability, the least-squares procedure was not used. In such cases, depending on the evidence of curvature noted in the scatter plot, any one of several line-fitting procedures may be used based on the recovery of representative variability that is estimated to exist within the record being reconstructed. As such, this recovered variability is unexplained. For the generalized procedure, the line of minimum absolute deviation (Zebrowski, 1979) was noted, as a general rule, to give results equivalent to the least-squares procedure when the explained variation being evidenced was greater than about 70 percent. Application of this method would otherwise provide reasonable recovery of estimated yet evidently representative variability when the explained variability was less than 70 percent. Either procedure was easily modified to accommodate evidenced curvature in the correlation relationship. The procedures being used were essentially the same as those demonstrated graphically by Ried, Carroon, and Pyper (1969). General methods used are well documented in Pollard (1977), Lapin (1983), in addition to Zebrowski (1979).

Veracity of reconstructed natural flow histories –

Within a region having consistent climatic factors that drive precipitation and streamflow, reconstructed, derived, and measured natural flow records should all be comparable. This comparability can be demonstrated primarily for longer-term precipitation histories within the region because precipitation is driven by a process that is naturally occurring. Further, precipitation is the principal climatic factor driving streamflow. Therefore, trends evidenced in natural flow records should show the same trends as those evidenced in precipitation records.

Trend analysis can easily demonstrate the consistency between records of each type. The methods used are related to a comparison of real trend and of the mass accumulation that occurs in the normalized annual time series. Real trend is an indication given by the equivalent trapezoid for the time series over the period of interest. The indication is valid only across the time interval being examined. The slope of the trend, determined in this way, is very sensitive to changes evidenced across the time interval and will readily show any consistency, or inconsistency, in the comparison of two similar records. For the determined period of interest, this comparison may be shown as either the linear trend expressed in each of the normalized annual records, or as the concurrent double-mass curve. Inconsistent trends will be evidenced immediately in the expressed deviations of the double-mass curve. The nature of this inconsistency is also easily seen, or evident, in the expression of slope for each of the trends shown for the normalized annual time series.

To begin the analysis, suitable stations must be chosen in forming the basis for the comparison. A suitable station is one that has a flow record, or precipitation record, for a gage that is in the vicinity of the gages, or locations, for which the restored natural flow records are being challenged. Such stations are therefore termed *basis stations*. However, given the limitations presented to this study, only one suitable flow record is available to establish this comparison basis. Therefore, this record must itself be checked to verify the natural flow consistency evidenced in the record. Gaged watersheds that have been subjected to progressive development will have flow histories showing an uncharacteristic deviation in mass accumulation when compared with the flow history of a nearby natural flow station. Given the specific conditions for suitability within this regional comparison of gaged flow histories for watersheds having natural flow, the records will show the same trend as that evidenced in precipitation histories covering the same period of interest for stations within the same region. Any loss of fidelity in the trend will be an immediate indication of unaccounted changes in watershed condition or inconsistencies in the natural flow derivation. Reconstruction of the natural flow history for a stream may be considered as effective and representative *if the trend for the period of interest shows no evident changes from that expected for a watershed under natural conditions*.

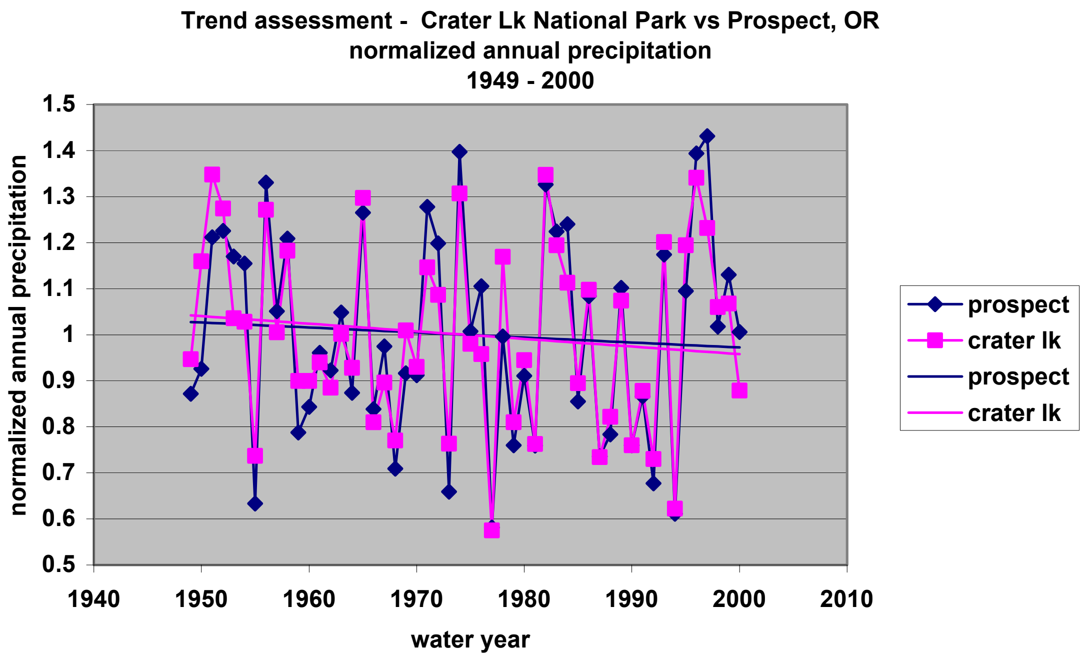
Sources of records being used –

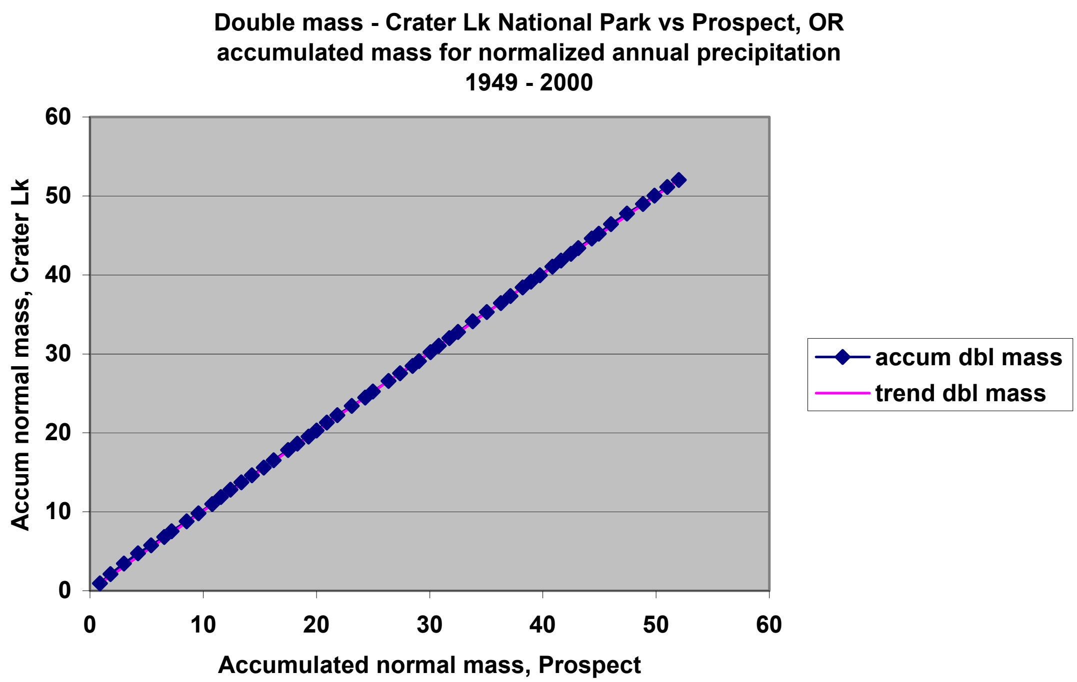
Stream gaging-station records are available from the water-supply papers published by the U. S. Geological Survey, or are accessible from comprehensive databases maintained by the U. S. Geological Survey, the Oregon Water Resources Department, or on compact disks as published by Hydrosphere. Streamflow records of principal interest included the gaged record for Rogue River above Prospect and for South Umpqua River at Tiller, both considered as basis stations. In addition, the gaged record for Sprague River near Chiloquin, and for Williamson River below Sprague River near Chiloquin, were primary records that were complete for the period of interest. Other needed records were supplied by the U. S. Forest Service for streams along the eastern flank of the Cascades.

Comprehensive databases providing precipitation records are available from the National Oceanographic and Atmospheric Administration and from compact disc records of U. S. Weather Bureau weather-data summaries that are published by Hydrosphere. In addition, long-term records were available from the Hydroclimatic Data Network. The meteorological records of principal interest essentially included Klamath Falls, Chiloquin, Sprague River, and Round Grove. The Klamath Falls precipitation record comprises a sequence documenting a continuous and nearly complete history from about 1906 to 2001. These records (except Chiloquin) were carefully examined and missing monthly values were researched, and recovered from Weather Bureau monthly summaries showing values for missing entries that had been previously estimated and published. Remaining missing values in these precipitation records were then statistically reconstructed, if required, by correlation with the record of one, or more, nearby precipitation stations. Precipitation records for Prospect and Crater Lake were also of principal interest and considered as basis stations.

The basis stations for comparison of restored natural flow –

To establish regional consistency in climatic factors, an assessment of trend evidenced for precipitation at Prospect, and at Crater Lake, was completed. Precipitation histories for each of these stations were examined and several missing monthly values reconstructed so that a complete precipitation history was available for each station. The comparisons are for normalized values of annual precipitation. Similar comparisons were also completed for each month, and these were checked to determine the representative nature of the results. Both records are stable as they are each from data collection platforms maintained at fixed locations. Results of the annual analysis for these time series are shown above. Of note is the indication that annual total precipitation shows a slightly greater declining trend on the east side of the Cascades, compared to that seen on the west side of the Cascades. The double-mass curve shows the mass accumulations have no deviations, which is expected for stable records.

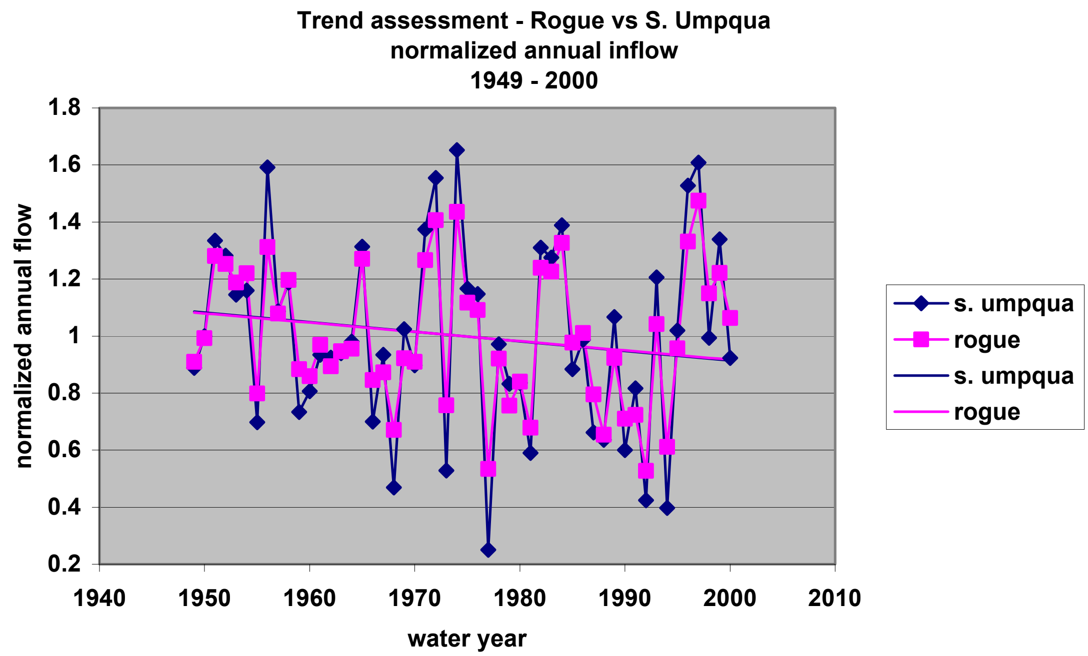


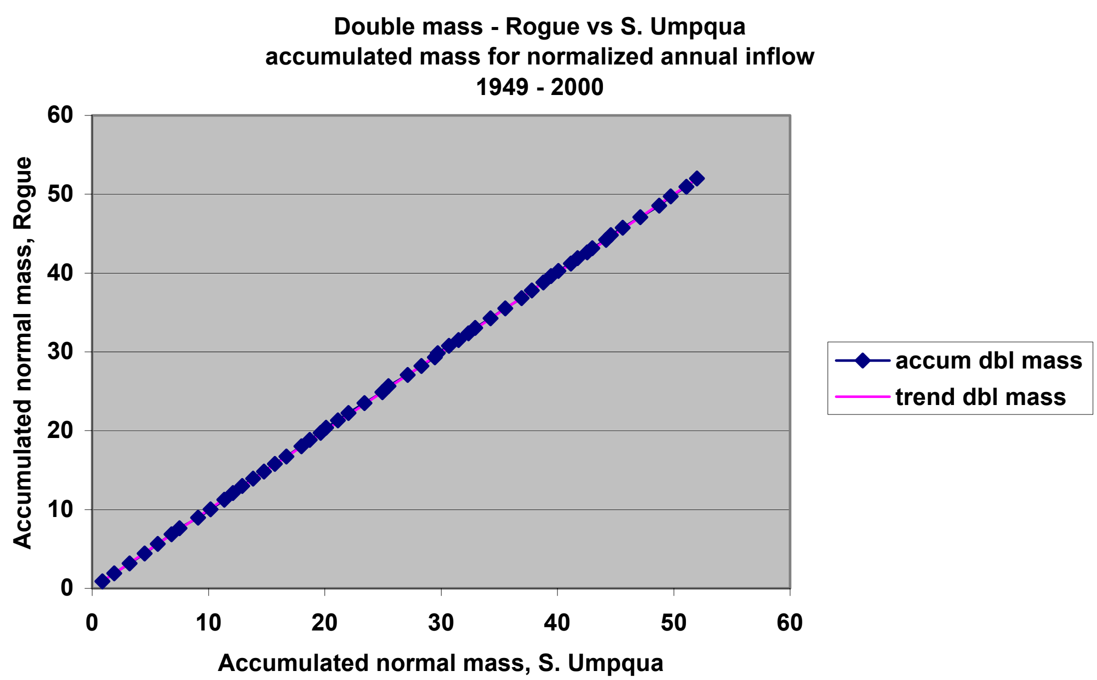


Upper panel shows indicated trend for annual time series of precipitation at Crater Lake and Prospect, Oregon. Lower panel shows the accumulated normal mass for annual precipitation at each station plotted as a double-mass curve.

Trend assessments were also completed to establish the representative nature of the record for the basis station challenging the veracity of reconstructed natural flows. This station is gage 14328000, Rogue River above Prospect, which was compared against the natural flow record of gage 14308000, South Umpqua River at Tiller. This second gage is in an independent west-side watershed north of the Rogue watershed. Of note, in the assessment shown on the following page, is the *nearly exact concordance* in trend evidenced for the annual flow time series of these two stations. The straight-line double-mass curve indicates these are stable, unaffected, natural-flow records.

The results in comparison of the natural flow record of the Rogue with that of the South Umpqua show the gage for the Rogue provides a representative record of natural flow that may be used as a basis in challenging the veracity of other records for restored natural flow determined at regionally nearby locations. The consistency in trends noted for these records also indicates climatic dominance is consistent within the region. The independently observed consistency in trends noted for the two longer-term precipitation records that were examined, Prospect and Crater Lake, indicates a divergence in trend that, over the period of interest, has decreased over time somewhat more rapidly on the east side of the Cascades than on the west. This same indication should be evident in time-series for restored natural flow in the upper Klamath basin that are compared with the natural flow record of the Rogue.





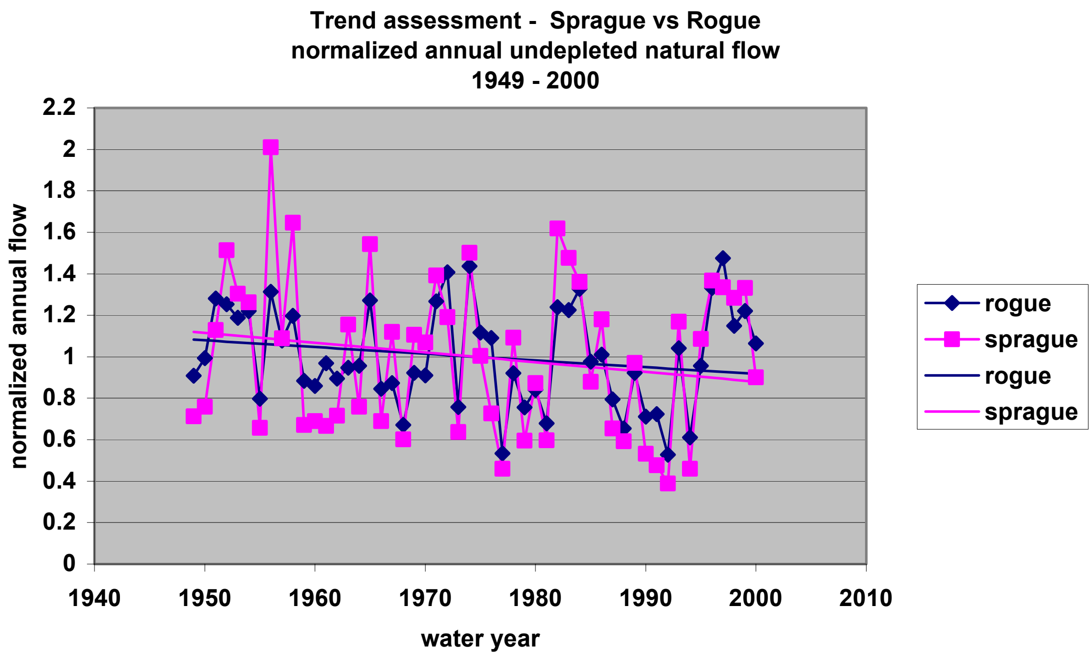
Upper panel shows indicated trend for annual time series of streamflow for the Rogue R. ab Prospect and S. Umpqua R. at Tiller, Oregon. Lower panel shows the accumulated normal mass for annual streamflow at each station plotted as a double-mass curve.

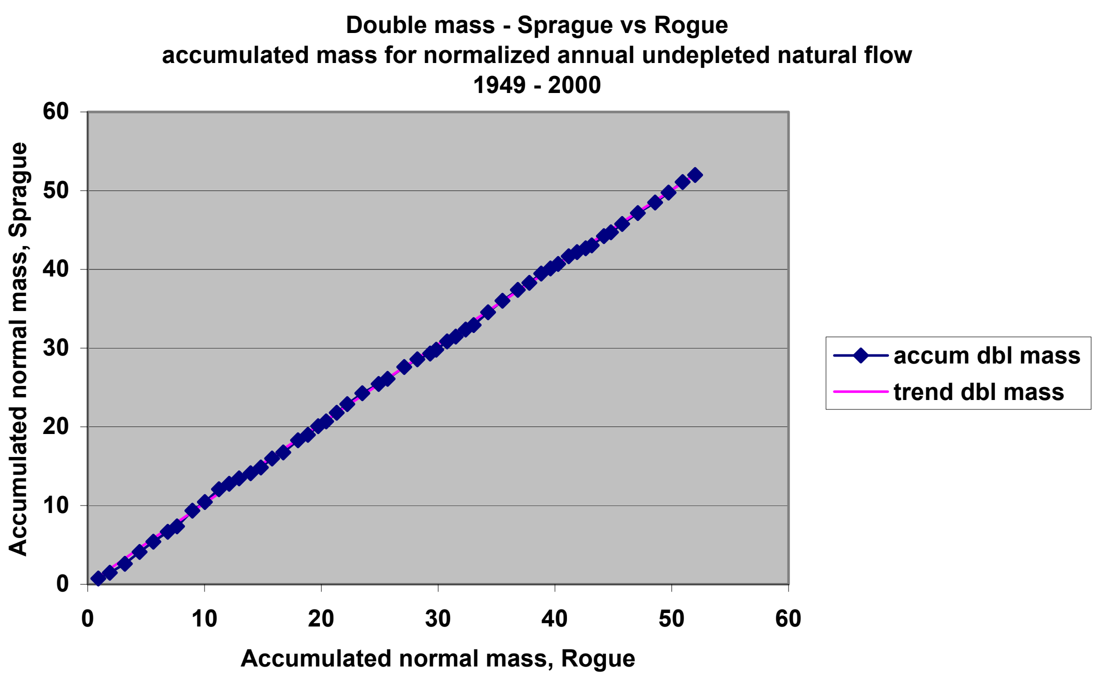
The Sprague and Williamson Rivers –

The assessment of natural flow for the Sprague and Williamson was unable to account for changes in watershed condition other than an accommodation of irrigation uses and reclamation of marshlands that would affect flow of the stream. An assumption in the evaluation of these areas has been that over the period of interest, there have been no marked changes in area for either irrigation or reclaimed marshland. Although essentially false, implementation of the assumption is conservative in the adjustment of the gaged flows throughout the 52 yr period of interest, and does not, thereby, tend to underestimate natural flow of these streams. The assumption implies that irrigated areas have been stable, more or less, even though no detailed information was determined to be available regarding the locations, timing of changes, and extent of increases in these areas. Further, other modifications in watershed condition that could not be evaluated may, or may not, have affected streamflow. These modifications would include changes in the rate of clear-cutting for logging and increases in the associated areas, increased clearing of land for range and pasture, and encroachment by Juniper. Nevertheless, the resulting analysis was able to determine a representative time series for the undepleted natural flow of the Sprague and Williamson. Evidently, this may be due, in part, to the compensation caused by the addition of irrigation depletions back to gaged flow and subtraction of natural losses for reclaimed marshland.

An examination of the normalized time series and double-mass curves for the Sprague, and Williamson below the Sprague, illustrate the nature of the derived results. Shown on the following page are the results in the assessment of the Sprague. These graphs clearly show the trend for the Sprague agrees with the indication given in the precipitation analysis. The indication given by the trend for the Sprague, which is confirmed by the trend for precipitation at Crater Lake, is that streamflow, and hence precipitation, is declining at a somewhat increased rate over time on the east side of the Cascades than that on the west side of the Cascades. The double-mass curve, above, indicates the reconstruction appears very good and shows no distinct deviations or abrupt changes in trend that would be characteristic of development and other changes within the watershed.

An examination of the results for natural flow of the Williamson below its confluence with the Sprague shows that with inclusion of the Williamson watershed above the Sprague, the determination of natural flow for the Williamson as an inflow to Upper Klamath Lake is also representative. Trends for each time series and double mass provide results that are consistent with those derived for the Sprague.



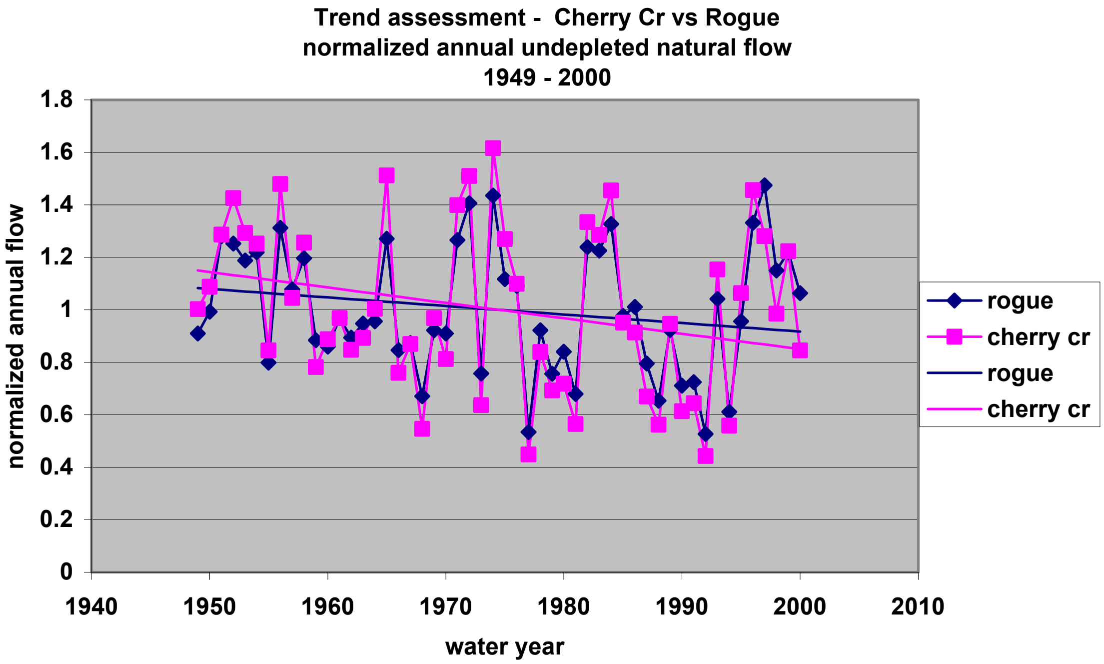


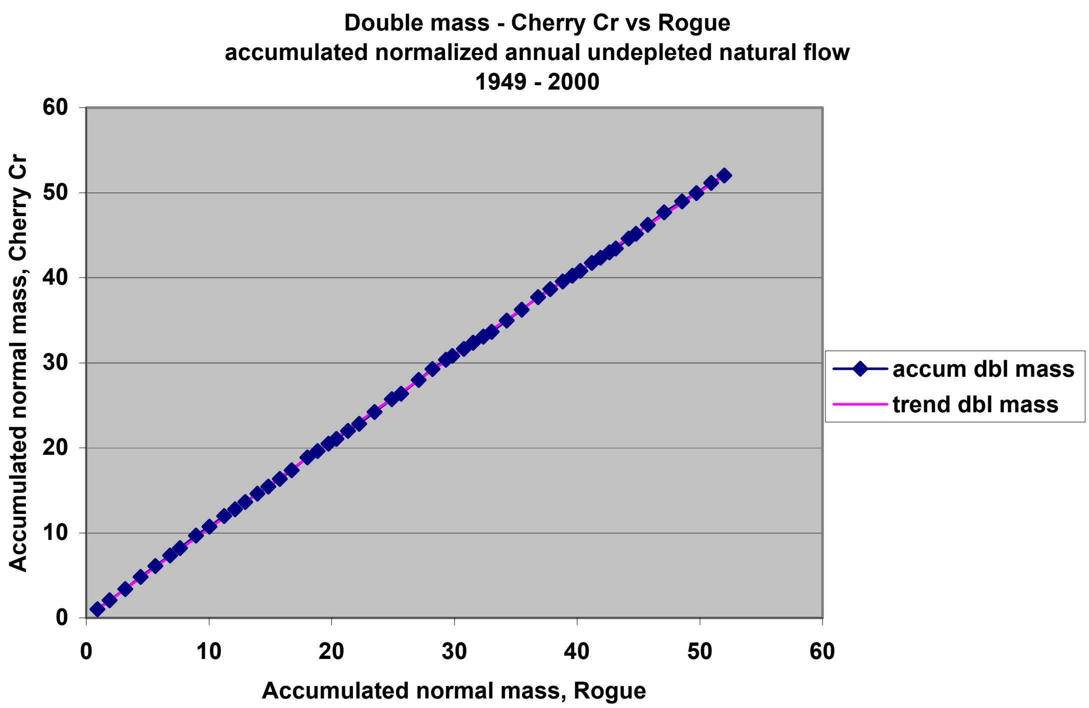
Upper panel shows indicated trend for annual time series of streamflow for the Williamson R. bw Chiloquin and Rogue R. ab Prospect, Oregon. Lower panel shows the accumulated normal mass for annual streamflow at each station plotted as a double-mass curve.

Cherry Creek –

Flow histories for several watersheds along the east flank of the Cascades have been estimated by transference of reconstructed gaged flows from nearby watersheds. Of special interest is the examination of reconstructed flow histories that form the basis of the transference, especially where the reconstructed flow histories did not need to be restored to natural flow. A typical reconstructed record from a type-watershed used in the transference is that of Cherry Creek. Records that are available for Cherry Creek are somewhat sparse yet sufficient for statistical reconstruction of a natural flow history covering the period of interest. Reconstruction of the record for Cherry Creek was based on monthly flows estimated from incidental flow measurements, or on a gaged flow record for years when that record was available. The correlation analysis in the reconstruction of the full time series used a special adaptation of the procedure for fitting the line of minimum absolute deviation, where the line of correlation was curved to accommodate the base-flow deviation observed, or suspected, in the scatter plot. The gaged history for the Rogue above Prospect was the principal station used in the reconstruction. Validation of the methods used, and the results obtained, was provided by the comparison of the reconstructed record with that of the Rogue. The record for the Rogue is also the basis station for challenging the veracity of the results. Hence, the adequacy in the reconstruction will be reflected in the degree to which the record for the Rogue appears as a surrogate in the reconstructed record for Cherry Creek.

The time series for normalized annual flow and resulting double-mass curve shows the recovery of information appears to be excellent for the reconstructed Cherry Creek time series. For the normalized annual flows, the decline in trend exhibited by the Cherry Creek annual flow time series agrees well with that for the east side of the Cascades observed in the comparison of precipitation histories for Prospect (on the west side of the Cascades) and Crater Lake. The double-mass curve shows the characteristic agreement that would be expected for comparison of two natural flow gages in essentially adjacent watersheds that are in stable natural conditions. The curve has no expressed deviations that would be indicative of changes in watershed conditions. An artifact visible in the double-mass curve is the slight curvature associated with the difference in rate of decline indicated by the trend demonstrated in the normalized annual time series. Results of these analyses are shown below.





Upper panel shows indicated trend for reconstructed annual time series of streamflow for Cherry Cr., a stream heading on the eastern flank of the Cascades, and Rogue R. ab Prospect, Oregon. Lower panel shows the accumulated normal mass for annual streamflow at each station plotted as a double-mass curve. Recovery of information for Cherry Cr. shows trend consistency with that evidenced east of the Cascades.

Appendix 1-4X. Methods for natural flow estimates in the Wood River Valley

Standard methodology –

<u>Sevenmile Creek</u> – below Short Creek and above Mares Egg Spring

Sevenmile Creek begins in the east Cascades south of Crater Lake, in the northwestern area of the Wood River Valley. The entire drainage area including Short Creek is approximately 50 mi^2. The two major sub-watersheds are Dry Creek, which is 13.3 mi^2 in area and is located on the north side, and Sevenmile Creek, which is 12.1 mi^2 in area and lies immediately to the south. About 58% of the Sevenmile Creek sub-basin is protected by the Sky Lake Wilderness areas, and 62% of the Dry Creek sub-basin is also wilderness. Only about 5% of entire drainage area is private land. Despite timber harvesting and road construction activities on USFS land, the magnitudes and peaking of streamflow in Sevenmile Creek above irrigation diversions area likely to not have been significantly affected from natural conditions (USDA, 1995). Therefore, gaged streamflow measurements taken above irrigation diversions are considered natural.

The headwater area of Sevenmile Creek begins along the east side of Cascade Ridge where an abundance of glacial till and loose unconsolidated volcanic material is located. The watershed is dominated by pumice soils, especially in the Dry Creek drainage, which has a high infiltration rate. Therefore, the fact that Sevenmile Creek has lower peak flows per drainage area than other western Wood River Valley stream is not surprising.

The high elevation peaks of Sevenmile Creek, particularly Klamath Point and Pelican Butte, are composite volcanoes composed of ashes and blocky basalt flows. These areas have very little drainage network, which implies groundwater recharge occurs here. Springs can be found at the valley bottom along the edge of wetlands, which are most likely fed by ground water recharge occurring in the Sevenmile drainage (USDA, 1995). The natural, synthetic time series developed for Sevenmile Creek attempts to account for surficial streamflow and water released by these springs at the bridge below Short Creek.

The USFS has maintained a daily recording streamflow gage on Sevenmile Creek below Dry Creek since October 1992. These values were measured above irrigation diversions, but these data are likely lower than the actual amount of water produced by the Sevenmile/Dry Creek watersheds, since the observation site is located on an alluvial fan. Consequently, a portion of flow has probably gone subsurface upstream at the top of the alluvial fan.

Several miscellaneous flow measurements were collected by the USGS in 1992-1993. Measurements were taken above Dry Creek, as well as downstream below Short Creek and several unnamed springs. These measurements are concurrent with the USFS record, so relationships were developed between the USFS gage and measurements taken below Short Creek in order to develop monthly total streamflow estimates for Sevenmile Creek below Short Creek from October 1992 to September 2001. February of 1999 was not estimated since the USFS gage was not continuous during this time period.

In general, Short Creek and the unnamed springs provided at least an additional 30 cfs to Sevenmile Creek. Only 2 streamflow measurements were collected when upstream diversions were not in use and were concurrent with the period of record of the USFS gage.

These measurements taken in autumn and were used to estimate baseflow contributions from the unnamed springs and Short Creek. Larger increases between the two gage sites were seen during spring runoff, which varied by at least 81 cfs, but unmeasured diversions between the two locations make it impossible to back-calculate the natural amount of water available with sufficient confidence. Part of the flow measured below Short Creek may also be accounting for water from the Sevenmile and Dry Creek watersheds that went subsurface and is not accounted at the USFS gage. The synthetic time series developed for Sevenmile Creek below Short Creek therefore accounts for the water produced by the unnamed springs, all the water observed in the USFS gage below Dry Creek, some of the water that went subsurface upstream of the USFS gage, and some water related to spring runoff in the intermediate area below the USFS gage.

The monthly total flow estimates below Short Creek were used to create a complete synthetic time series for Sevenmile Creek between October 1947 and September 2001. This correlation analysis was completed against the Rogue River above Prospect gage on a month-by-month basis. Good correlations were found between the Sevenmile estimates and the Rogue River above Prospect gage, and sufficient variability was apparent in each month. The combination of the original monthly total streamflow estimates and those derived from the line of minimum absolute deviation for each month composes the synthetic time series for Sevenmile Creek below Short Creek, with one exception.

Several instantaneous streamflow measurements were collected below Short Creek by the USGS between August 1949 and October 1962. Of these values, most can be considered natural, because the upstream irrigation canal was noted as being "dry." For the other measurements where the diversion canal was not dry, a flow measurement was collected for the diversion canal. By adding together these streamflow and diversion flow measurements, these streamflow measurements were naturalized. All of these natural values were used to rescale the Rogue River above Prospect and Red Blanket Creek daily gage records to estimate monthly total flows for several autumn months between 1950 and 1962. The monthly totals found by rescaling the two gaged records yielded very similar results, generally within 10% of each other. Even though only 2 of these measurements were noted as "baseflow" by the USGS, these estimates will be referenced to as baseflow estimates since they were only for early autumn months.

These baseflow month estimates were considered accurate for natural flow in Sevenmile Creek below Short Creek. The month-by-month least-squares procedure was attempted using these estimates, along with the estimates generated between 1992 and 2001. The September and October coefficient of variation, or r^2 values, reduced significantly upon their inclusion from those found when using only the 1992-2001 estimates. The reason for this reduced variability was that baseflow measurements below Short Creek may be quite stable due to the influx of spring flow. The baseflow estimates generated between 1992 and 2001 are more dependent on the baseflow recession rate at the USFS gage. The baseflow recession rate at the USFS gage most likely has more variability than the baseflow rate below Short Creek. The gage below Short Creek is more dependent on spring-fed flows than the USFS gage, and the USFS gage may be underestimating baseflow due to the alluvial fan location. Since greater variability is considered to more accurately represent natural streamflows, these less variable monthly total flow estimates were omitted in the least-squares line development. These values were considered accurate, though, as they directly resulted from gaged information. Therefore, they were used in the final synthetic time series in place of values derived using the MAD line to provide additional calibration to the Sevenmile Creek synthetic time series.

Threemile Creek – at outlet

The Threemile watershed lies just south of the Sevenmile drainage and totals 9.7 mi^2 in area. Threemile Creek flows perennially into Crane Creek on the valley floor, and streamflow is dominated by spring snowmelt runoff. The geology of the watershed is similar to Sevenmile, with cinder cones defining the northern and southern ridge tops and abundant loose unconsolidated volcanics. High infiltration rates in these soils limit streamflow yield. The southern ridge tops probably provide ground water recharge for springs on the valley bottom, such as Mares Egg Spring.

The Threemile Creek watershed is partially protected by the Sky Lake wilderness of the Winema National Forest. About 50% of the Threemile watershed lies within the wilderness area, while the remaining portion is non-wilderness. Despite some timber harvest and road construction in the watershed, there appears to be no effect from these activities on timing of peak flows. Although Threemile Creek was only intermittent previously, due to water going subsurface into the alluvial fan upstream of the confluence with Crane Creek, the current perennial flow has been attributed to natural channel downgrading that occurred during the 1964 flood. During this storm, the channel bottom was lowered by about 10 ft, thereby bringing the stream closer to the water table (USDA, 1995). Therefore, the magnitude and timing of flows observed by gaged streamflow measurements are considered to be natural.

The USGS collected instantaneous and streamflow measurements about once a month between September 1964 and October 1967 at an appropriate upstream location that is not on an alluvial fan. The USGS created monthly total flow estimates from these numbers (Hubbard, 1970). The USGS also collected annual peak flow measurements mainly between water years 1965 and 1974, so the peak flow measurements allowed for precise reconstruction of monthly totals between 1964 and 1967. Reconstruction of monthly total flow was completed by rescaling the Varney Creek and South Fork Rogue River (S.F. Rogue + S.F. Power Canal near Prospect) gages. The estimates generated from each gage varied slightly, particularly in the late summer and early autumn, mainly because Varney Creek exhibited a lack of surficial baseflow, unlike Threemile Creek and South Fork Rogue River. Otherwise, the reconstructed values were similar to those developed previously.

The USFS also collected miscellaneous flow measurements between December 1991 and May 1997. Monthly total estimates were generated for several months from the Rogue River above Prospect and Cherry Creek gages. All estimates were used to develop correlations between the extended synthetic time series for Cherry Creek (see Cherry Creek). Specific month correlation equations provided additional calibration for March through July, while a generic equation encompassing all estimates was applied to the other months. The final synthetic time series yielded very similar results to expected values.

On July 29, 1992, the USGS collected instantaneous streamflow measurements at 2 different locations. One measurement was taken at the old-USGS gage location, where all other USFS miscellaneous flow measurements were taken, while the other measurement was taken upstream. The downstream gage location is unfortunately located on an alluvial fan, whereas the upstream location is in a V-notch valley. As is expected, the upstream value of 0.83 cfs is almost 4 times higher than the 0.21 cfs measured on the alluvial fan. Apparently a significant amount of water goes subsurface from Threemile Creek due the alluvial fan. The majority of available streamflow measurements were taken on the alluvial fan, and since there is only one day that concurrent measurements were taken at the 2 locations, estimating the lost water for inclusion in the Threemile synthetic time series is not possible with any accuracy. Therefore, not all water produced by the Threemile Creek watershed could be accounted without further field work, but the synthetic time series developed is representative of flow available on the surface. The water that became subsurface at the alluvial fan is most likely captured and released through evapotranspiration by the wetlands 2/3 mile downstream.

Nannie Creek – at outlet

Nannie Creek is only 3.5 mi^2 in area and lies on the west side of the Wood River Valley, just south of Threemile Creek. While only 9% of the drainage has equivalent clearcut acres, caused by harvesting over the past 25 years, the most significant change to hydrologic processes in the watershed has resulted from alteration of the fire regime. Fire suppression in the Nannie Creek drainage has increased the amount of area with 70-100% canopy closure from 2 to 27% since 1940. This increase in canopy cover may be altering the peaking of snowmelt runoff, since less sunlight reaches the snow pack, but these effects have yet to be quantified (USDA, 1994).

Since only limited information was available regarding effects to streamflow, a synthetic natural time series was made assuming USGS gaged streamflow measurements were not significantly altered from natural conditions. Instantaneous streamflow measurements were collected by the USGS between August 1964 and October 1967. Monthly total flow estimates were generated by rescaling daily gaged records from Varney Creek, which had similar peaks and baseflow regime as Nannie Creek, and South Fork Rogue River (S.F. Rogue + S.F. Power Canal near Prospect). The USFS also estimated baseflow and peak measurements in 1993 (USDA, 1994), but the monthly total estimates developed from these data were not considered accurate enough for use in correlation equation development. These estimates were only used to verify calculated values.

Very few monthly total streamflow estimates could be generated. The monthly flow estimates usable in completing a correlation analysis were restricted to values above zero, since several months had no flow, so only 10 data points (monthly totals) were available for the analyses. Only one general equation was developed to make synthetic time series for Nannie Creek. This equation relates concurrent monthly totals against Cherry Creek data to create a synthetic time series from October 1947 to September 2001.

The quality of the Nannie Creek synthetic time series is obviously lower than other Klamath Lake basin watersheds. The reasons for a lower quality record are:

1. A continuous daily gage record was not available.
2. Very few monthly total flows could be estimated.
3. The estimates made were only for 1964-1967, rather than more than one time period.
4. Month-specific equations could not be determined due to lack of data.

Despite the inability to calibrate these numbers with more accuracy, the monthly total estimates used in correlation exhibit sufficient variability to represent the natural streamflow of Nannie Creek. During the period of record of gaged data, between 1964 and 1967, a complete range of streamflow measurements were observed in Nannie Creek. In December and January 1964, a significant flood event occurred across the far western states, which is apparent in the December 1964 Nannie Creek streamflow measurements. For low flows, Nannie Creek was observed to be dry in September of 1966 and 1967. Intermediately, 8 other monthly flow estimates defined the typical flow regime of Nannie Creek. Though the synthetic time series for Nannie Creek is not based on numerous data points, a representative time series was generated by capturing sufficient variability.

<u>Cherry Creek</u> – at outlet

The Cherry Creek drainage is 16 mi^2 in area and lies on the west side of the Wood River Valley, just south of Nannie Creek. The watershed aspect is east-west, and the flow direction is to the west. The original stream split into three main channels atop an alluvial fan below the watershed outlet, which either flowed into Fourmile Creek or directly into downstream wetland areas. Flow is now diverted for irrigation purposes near the watershed outlet or is channelized into Fourmile Canal. More than half of the watershed is protected by the Sky Lakes Wilderness and has been relatively unaltered by land management activities. The remaining area has experienced minimal harvest activity during the last 25 years, and only 1% of the entire watershed has been affected by clearcuts (USDA, 1994).

The USFS has maintained a daily recording gage on Cherry Creek since October 1992. Unlike other Wood River Valley tributaries, the available gaged data for Cherry Creek were taken in an excellent location, within a constricted valley above the watershed outlet. These data are considered to be highly reliable natural streamflow measurements due to their prime measurement location and the consideration that flows at this location have not been significantly altered due to land management activities (USDA, 1994).

Instantaneous streamflow measurements were made by the USGS between 1964 and October 1967. Monthly total estimates were generated from these data by rescaling the Varney Creek and South Fork Rogue River (S.F. Rogue + S.F. Power Canal near Prospect) gaged records. The estimates generated from each gage varied slightly, particularly in the late summer and early autumn, mainly because Varney Creek exhibited a lack of surficial baseflow, unlike Cherry Creek and South Fork Rogue River.

The USFS also collected streamflow measurements between December 1991 and July 1992. Total monthly flow estimates were made by rescaling the Rogue River above Prospect daily gaged record. This was the only record rescaled because it was the only natural daily flow recorded during that time period near the Wood River Valley. These monthly total flow estimates were combined with the 1960s estimates and gaged records to develop the synthetic time series.

Gaged and estimated monthly totals were used to create a complete synthetic time series for Cherry Creek between October 1947 and September 2001. The derivation procedure used the same generalized correlation procedure modified for the line of minimum absolute deviation to estimate values between October 1947 and September 1992. This correlation analysis was completed against the Rogue River above Prospect gage on a month-by-month basis. Relatively good correlations were found between the Cherry Creek estimates and the Rogue River above Prospect gage. Despite having several low r^2 values in the summer months of July and August, trends exhibited in the gaged data are quite prevalent and are reproduced in the synthetic data.

Cherry Creek has geologic features typical of the eastern slopes of the Cascades. The headwaters begin with steep rock escarpments and talus slopes that drain into the Cascade summit, characterized by broad, flat plateaus with abundant kettle lakes and wet meadows. Steep, heavily forested slopes of the lower watershed descend to the lacustrine environment of the Upper Klamath Lake Basin (USDA, 1994). The same land-forming processes occurred all along the east side of the Cascade Range; therefore all western Wood River Valley streams are characterized by basaltic lava material overlain by pumice ash deposits. As a result, the complete synthetic time series for Cherry Creek was used to generate synthetic time series for these other watersheds under the following premises:

1. Similar geology and sedimentation leads to similar permeability and water-bearing capacity.
2. Streams on the east side receive less rainfall than the watersheds to the west, where the majority of gaged streamflow data are available, so deriving a quality synthetic record from Cherry Creek is more accurately relatable to other Wood River Valley tributaries than using data from over the ridge.
3. The gaged data available for Cherry Creek are considered highly representative of all the water produced by the Cherry Creek drainage, since the gage location was placed in a constricted, V-notch valley.
4. The synthetic time series for Cherry Creek was used in generating time series for Threemile Creek, Nannie Creek, Rock Creek, and Moss Creek.

Instantaneous streamflow measurements were made by the USGS between 1964 and October 1967. These data are available from the OWRD website, but cross-checking with the original data published by the USGS revealed several errors in the OWRD data. These errors were corrected, and updates related to the other watersheds were made based on the corrected Cherry Creek data.

<u>Rock Creek</u> – at Upper Klamath Lake

The Rock Creek drainage is 16.5 mi^2 in area and lies on the west side of the Wood River Valley, just south of Cherry Creek. About 33% of the watershed is within the Sky Lakes Wilderness, and only 3.6% of the watershed has equivalent clearcut acres. There are no diversions into or out of Rock Creek. The streamflow measured at the outlet is therefore considered relatively unaffected by land management practices or diversions (USDA, 1994).

The USGS, USFS, and OWRD have collected numerous miscellaneous flow measurements on Rock Creek. Similar to other watersheds, the USGS collected instantaneous streamflow measurements between December 1964 and October 1967. These data were previously used to develop monthly total estimates (Hubbard, 1970), but several months were redeveloped by rescaling Varney Creek and South Fork Rogue River daily gages. In the 1990s, OWRD measured streamflow between December 1991 and May 1993, and the USFS measured streamflow between December 1991 and May 1997. These measurements were combined in order to make monthly total streamflow estimates for several months between 1992 and 1997.

The measurement location of the USFS (1990s) data is upstream from the USGS (1960s) site. This downstream site is located on an alluvial fan where Rock creek meets the Klamath Lake basin. The USGS measurements are most likely to underestimate the full amount of water being released from the Rock Creek drainage due to the location of the gage measurements and the likelihood some water had gone subsurface at the top of the alluvial fan. Unfortunately, there are no concurrent measurements between these two sites, so further field work would be necessary to adjust the 1960s data to a more natural condition. Consequently, the 1990s estimates were relied on more heavily in the development of natural streamflow correlation equations.

Correlation equations were developed to create a Rock Creek synthetic time series from October 1947 to September 2001. A general correlation based upon the synthetic natural time series for Cherry Creek was used for most months, but month-specific equations were developed for May through September. Despite being similar to Cherry Creek in size and average precipitation, the Rock Creek drainage produces far less streamflow. The reason for the lower flow levels may be based on slightly different geology and water retention capabilities of the watershed (USDA, 1994). The Rock Creek synthetic time series is considered to be natural and representative of water that would be released to Upper Klamath Lake by the Rock Creek drainage.

Moss Creek – at Upper Klamath Lake

The Moss Creek watershed is 8.3 mi^2 in area and drains into Ball Bay of Upper Klamath Lake. About 77% of this watershed area is protected by the Mountain Lake Wilderness area of the Winema National Forest, and an additional 12% is within National Forest Boundaries. The remaining 11% is most likely privately owned. In comparison to other neighboring watersheds, land management activities and road development in this watershed probably have not significantly affected streamflow, since areas with far less wilderness have been attributed with relatively no effects.

The USGS measured streamflow in Moss Creek occasionally between December 1964 and October 1967, but did not denote whether diversions occurred upstream of this site. There is only one water right in the Moss Creek watershed, and the water right certificate was established for irrigation purposes allowing a maximum of 1.5 cfs to be diverted. The gage record shows Moss Creek going dry in the summer and early fall. This water right probably was not used during these months. Any diversions during snowmelt runoff months would have minimal effect on total monthly flow. Since the majority of the Moss Creek drainage has been unaltered by diversions or land management activities, the few gaged streamflow measurements available are considered natural.

The USGS gaged streamflow measurements between December 1964 and October 1967 were used to develop total monthly streamflow estimates by rescaling Varney Creek and South Fork Rogue River (S.F. Rogue + S.F. Power Canal near Prospect) gaged records. The USGS has developed monthly total flow estimates between October 1964 and September 1967 (Hubbard, 1970). For the other watersheds where estimates had already been developed by the USGS (Rock Creek and Fourmile Creek), the redevelopment completed showed very similar results in the majority of months.

One general equation that accounts for low and high flows was developed and used to generate the synthetic time series for Moss Creek. Sufficient data were not available to create month-specific equations. A season-specific equation was attempted to account for spring runoff, but no further calibration was found from this equation.

The inadequacies of this time series are analogous to those of Nannie Creek. Despite the inability to calibrate these numbers with more accuracy, the monthly total estimates used for correlations exhibit sufficient variability to represent natural streamflow in Moss Creek. Once again, the occurrence of a significant flood event and observations of Moss Creek being dry represent the full extent of streamflow variation expected in a 50-year period. Thus, even though the synthetic time series for Moss Creek was not based on numerous data points, a representative time series was generated by capturing sufficient variability.

Exceptions to Standard Methodology –

Not all watersheds in the Wood River Valley have the same basin characteristics. Several watersheds have unique geology or dominant flow regimes. One particular watershed has streamflow data available, but the data represent an altered state due to the presence of a dam and diversions out of the reservoir. The standard methodology for developing a natural time series is inadequate for such watersheds.

To quantify the natural inflow to Upper Klamath Lake from these basins, alterations to the standard methodology were made. Watersheds that had unique geology, Annie and Sun Creeks, were developed using streamflow along with precipitation data. Denny Creek was developed in a similar fashion since the flow regime is dominated by winter precipitation rather than snowmelt runoff, unlike most Wood River Valley basins. Finally, the Fourmile Creek natural time series was developed by naturalizing the available streamflow measurements before proceeding with a more standard process as previously described. A detailed description of each uniquely addressed watershed follows.

<u>Annie Creek</u> – at gage south of Crater Lake National Park / Winema National Forest boundary

The geology of the Cascade Range varies within the Wood River Valley. Between 4,000 and 7,000 years ago, collapse of Mount Mazama formed the current day caldera of Crater Lake. The pre-collapse elevation of Mount Mazama was likely more than 12,000 feet above sea level. The steep slopes of Crater Lake show abundant evidence of large glaciers, particularly on the south side. The south valleys are U-shaped and have the smooth parallel sides characteristic of glacial channels. During the final eruptions of Mount Mazama, glowing pumice and scoria lava flowed down the south side into the Annie Creek and Sun Creek drainages (Frank et al, 1969; Williams, 1956). Because the geology of these watersheds is uniquely different compared to the other Wood River Valley drainages, the standard process for quantifying natural streamflows was inadequate.

The Annie Creek drainage is 28.5 mi^2 in area and drains south, with headwaters located on the south side of Crater Lake. The streamflow hydrograph for Annie Creek is characterized by spring-fed flow in the autumn and winter and snowmelt runoff driven spring and summer time flows. The spring flow dominating this watershed may even have originated in Crater

Lake. The extended period of record for Annie Spring, near the Crater Lake National Park Headquarters, was invaluable in developing a synthetic time series for Annie Creek.

The USGS has collected streamflow gaged records at Annie Spring since June 1977. Similarly, the USFS has maintained a gage at the National Park/National Forest boundary since October 1993. Some water is diverted at the Crater Lake National Park Headquarters for residential uses, and these diversions are quantified and available in the USGS Water Resources Data Publications for Oregon. From the available gaged data, a natural synthetic time series was initiated for Annie Creek by performing month-specific linear correlation analyses that had been modified for the line of minimum absolute deviation or a generally similar fitted line.

These month-specific correlations were created between Annie Creek data and the naturalized Annie Spring data. The Annie Creek data were not naturalized, per se, before correlating with Annie Spring, but the upstream diversions were expected to have inconsequential effect on the Annie Creek gage, which represents flow resulting from a large drainage area. There are no other diversions above the Annie Creek gage location, as the intermediary land is part of Crater Lake National Park. The correlations for most months exhibited r^2 values around 0.90, with March and November exhibiting the worst r^2 values around 0.60. This correlation analysis extended the Annie Creek record back to June 1977, but estimates needed to be made back to 1947.

Several techniques were attempted to develop the earlier years. Relationships between Annie Spring and Annie Creek data with other nearby gages unfortunately exhibited no correlation. Luckily, near the crest of Crater Lake within the Annie Creek drainage, the U.S. Department of Interior National Park Service (NPS) has collected extensive temperature and precipitation data at the Carter Lake National Park Headquarters. The Crater Lake temperature and precipitation gage data extends unbroken back beyond 1946, and data is still being collected today. These data were found to be very valuable for correlations in lieu of a gaged watershed with similar geologic features.

Crater Lake precipitation and temperature data were used to develop the early years of the synthetic time series for Annie Creek. Correlations were completed against Annie Creek monthly streamflow totals. Even though the Annie Creek record was extended back to1977, the 1977-1992 streamflow estimates were not considered sufficiently accurate to be used in correlations against weather data. Annie Creek gaged streamflow data were obtained for water year 2002 and were included in the remaining correlation analyses. Therefore, only 10 years of gaged streamflow data were available for developing the initial years of the time series.

Crater Lake temperature data showed definite trends as to which month the peak spring runoff had occurred. The peak runoff month for 1948-1976 was determined by employing a monthly average temperature rule. This rule generally defined the month with the largest spring runoff as being the second spring month with average temperature above 33°F, with a few caveats. This rule provided the backbone for estimating the early years, when coupled with the ability to estimate total discharge in the peak month.

The available weather data were used to develop peak monthly total flow for 1948-1976. A good correlation (r^2 value of 0.98) was found between lagged total winter precipitation and total streamflow in the peak runoff month. Total winter precipitation was defined as total precipitation between the months when average temperature fell below 33°F through the peak runoff month. The winter precipitation totals were lagged over 5 years, since the flow in Annie Creek is not directly related to only the previous winter. The accumulation of snow and rain in Crater Lake recharges ground water aquifers, which provide streamflow to Annie Creek. The movement of subsurface water can be quite slow, depending on the regional geology, and can affect ground water discharge to the surface for several years. The lagging of winter precipitation totals mimics the combination of direct snowmelt runoff from that winter's total precipitation plus the reappearance of ground water in Annie Creek.

The baseflow months of Annie Creek are very distinctive. Streamflow in the late summer and early autumn months declined at a similar rate every year. Since incidental streamflow measurements in August, September, and early October were available for 1949 through 1973, the baseflow level could be estimated for each year.

By having the peak runoff and baseflow estimates, the intermediate months could be estimated. Month-to-month correlations were developed where the flow in one month could define the total flow in the following month when combined with precipitation data. Equations were developed to generally define the following month, where relationships between gaged flows and precipitation qualified whether a month-to-month discharge equation or a precipitation driven equation should be used to estimate monthly total flow. Precipitation driven equations were used mostly in the autumn months, before the average monthly temperature fell below 33 F, and were not employed in sub-freezing months. Of course, rain-on-snow events occur in the region and needed to be addressed.

The effects of winter storms and rain-on-snow events were investigated. A significant flood event occurred December 24, 1996-January 3, 1997, during which the USFS maintained a daily recording stream gage. Assuming the gage did not malfunction, which does not seem likely from the peaking evident in gaged daily streamflow data, then apparently Annie Creek does not experience as severe floods as observed elsewhere. Large increases in monthly total flow that were observed by nearby gages were not seen in the Annie Creek gage. The Rogue River above Prospect monthly total flow increased 189% from November to December in 1996. Similarly, the Sevenmile Creek near Fort Klamath total monthly flow increase by 129%. The total monthly flow in Annie Creek fell by about 1% between November and December 1996. Flows in Annie Creek generated by this winter storm were within normal winter streamflow variation and did not exceed typical peaks of spring runoff flows. Despite the similarly shaped daily streamflow hydrographs, the effect of this rain-on-snow event on Annie Creek monthly total streamflow was minimal compared to other nearby watersheds.

The winter storm of December 29, 1995-January 1, 1996 was also captured by Annie Creek streamflow records. Monthly total streamflow increased from November to December in the Rogue River above prospect and Sevenmile Creek near Fort Klamath gaged records by 317% and 318%, respectively. Annie Creek experienced a 165% increase in monthly total flow. The effects of this storm on Annie Creek are more prevalent than those from the December 1996 event, but estimating these effects without streamflow measurements would be highly data intensive and not necessarily accurate. Antecedent snow pack conditions would need to be known, along with the precipitation type (rain or snow) and snow-line elevation of each storm to attempt incorporating the dramatic effects of winter storms. Therefore, the effects of rain-on-snow events were not incorporated into the monthly synthetic time series, with one exception.

The effects of the December 1964 storm were included in the Annie Creek synthetic record. Monthly total estimates were developed for this storm by comparing the effects of the December 1995 storm on the Rogue River above Prospect gaged record and the Annie Creek record. This particular storm was estimated and included because of the large affect this storm had on streamflow across the Wood River Valley. Inclusion of these estimates was an attempt to further calibrate the synthetic time series for Annie Creek.

Additional instantaneous streamflow measurements were available to estimate streamflow between May 1991 and September 1992. Work related to a report on water quality of Wood River subbasins (Hathaway et al, 1993; Hathaway, 2003) provided streamflow measurements in Annie and Sun Creek. The USGS also collected several instantaneous flow measurements at the same Annie Creek location during that time period. When these measurements were combined, streamflow had been measured at least once a month between May and October 1991 and between March and November 1992. The estimates found using these miscellaneous flow measurements were highly similar to those found using the correlations against Annie Spring. The monthly total estimates generated from miscellaneous flow measurements were considered more accurate than the Annie Spring generated estimates and thus were used in the final synthetic file.

Development of the natural synthetic time series for Annie Creek took extensive time to gather available data and complete correlation analyses. Also, all data used in this development were measured within the Annie Creek basin. In the end, the natural synthetic record for Annie Creek is believed to be sufficiently representative, despite the inability to predict the effects of rain-on-snow events. This synthetic record provided the basis for the Sun Creek watershed, located immediately to the east, and was used with ample confidence in its reliability.

<u>Sun Creek</u> – at Crater Lake National Park/ Sun Pass State Forest boundary

All land upstream of the gage location on Sun Creek is protected wilderness within Crater National Park. There are no diversions from the stream within the park, and the contributing drainage area for the gage is 11.1 mi^2. The same glacial and volcanic processes that formed the geology of Annie Creek occurred in Sun Creek. Due to the similar geology, the streamflow hydrograph that occurs in Sun Creek is likely to be more similar to Annie Creek than any other stream. Hence, the Annie Creek synthetic time series provided the basis for the estimated natural streamflow of Sun Creek.

Very little streamflow information is available for Sun Creek. Hathaway and Todd (1993) collected several years of miscellaneous streamflow measurements on Annie Creek and Sun Creek. From the concurrent measurements at the most upstream and natural sites, highly similar flows were observed in the two streams. From these data, the flow in Sun Creek was estimated to be 25% of the magnitude of Annie Creek flow. To create a synthetic time series for Sun Creek, the Annie Creek time series was rescaled by 25.17% based on concurrent gaged data. Total monthly streamflow estimates were generated for May -October 1991 and

March – November 1992 using the miscellaneous streamflow measurements from Hathaway and Todd. In most cases, these estimates were used in place of the estimates generated by rescaling the synthetic time series for Annie Creek, since these estimates were considered more accurate due to their basis of actual gaged Sun Creek data.

<u>Fourmile Creek</u> – at Upper Klamath Lake

Fourmile Creek is located on the east side of the Wood River Valley, immediately south of Rock Creek. The entire Fourmile Creek watershed drains approximately 105 mi^2, and flows directly into the marshlands near Pelican Bay of Upper Klamath Lake. There are three major subwatersheds known as Fourmile Creek, Fourmile Creek above Seldom Creek, and Lost Creek. The Seldom Creek subwatershed contains Lake of the Woods and only releases water into Fourmile Creek intermittently. Of the entire watershed area, 32% is contained within wilderness areas of the Winema and Rogue River National Forests and has remained in a relatively unaltered state, 2% is private land, and the remaining 66% is non-wilderness National Forest Land.

The water and land of Fourmile Creek watershed has been actively managed during the last century. Timber harvesting in the drainage began around 1900. The south and southwest slopes of Pelican Butte, Fourmile Flat area, and the lower Lost Creek drainage were harvested in the early 1900s, and harvest activities were greatest in the 1960s, when partial timber removal occurred on at least 7.5 mi^2. Timber harvesting has continued since then, but to a lesser extent. Since canopy closure has not been significantly reduced in the Fourmile Creek watershed, it is considered unlikely that timber harvesting has had a measurable affect on streamflow (USDA, 1996).

On the other hand, a definite change in streamflow variability has occurred due to the presence of Fourmile Dam. Fourmile Creek above Seldom Creek contains Fourmile Lake, which is actively managed by operation of Fourmile Dam. Not only is water held back by the dam, water is diverted out of Fourmile Lake by Cascade Canal, which transports the water out of the Fourmile and Klamath basins. Water from Cascade Canal is carried west over the Cascade Range into Rogue River basin and is discharged into North Fork Little Butte Creek upstream from Fish Lake.

Originally, Cascade Canal was composed of earth and rock. Upgrades were made in 1915 to build the concrete structure still in use today. Upon completion of Fourmile Dam in October 1922, the capacity of the natural lake was increased, and the flow regime in Fourmile Creek stabilized to present conditions.

Within the last few years, no active releases to Fourmile Creek have been made. AN assumption is that the water from Fourmile Lake was only directly connected with Fourmile Creek if the spillway was crested. In the past, flash boards have been used on Fourmile Dam to increase the capacity. Therefore, only very large flood waters were assumed to contribute directly to flow in Fourmile Creek.

Streamflow in Fourmile Creek may still have been replenished by water retained behind Fourmile Dam. The Fourmile Lake/Dam system is anticipated to recharge of surficial aquifers that contribute to flow downstream in Fourmile Creek. This seepage could not be quantified from available stream gage records, and thus was considered to be minimal for lack of better data.

The Fourmile Dam and Cascade Canal regulations have affected the timing, duration and quantity of streamflow in Fourmile Creek by disconnecting a large headwater area. To estimate the natural streamflow of the Fourmile Creek watershed, the total flow captured and diverted from this headwater area needed to be quantified and added to the streamflow generated by the remaining connected area. Using reservoir content and Cascade Canal diversion data, the inflow to Fourmile Lake was estimated. These data were then added to the available gaged records in order to create natural monthly streamflow totals.

The streamflow records for Fourmile Creek are available from the USGS and USFS. Monthly total streamflow estimates were made from the USFS data, which constituted miscellaneous instantaneous streamflow measurements in the spring and summers between April 1992 and May 1997. The USFS gage site is located in a narrow valley ¾ mile above the Seldom Creek confluence, and this site includes all water produced by the upstream watershed less the area above Fourmile Lake. Alternatively, the USGS maintained a daily recording streamflow gage on Fourmile Creek near Rocky Point (below Varney Creek) between October 1964 and September 1967. The measurement location of the USGS gage is situated in an alluvial valley bottom, most likely with lacustrine deposits. Some water produced by the Fourmile Creek watershed has likely already gone subsurface at this location. Neither gage location is perfect for use in developing a larger synthetic time series, but the available gage data still proved to be highly beneficial.

The USFS data accurately depict the water produced above Seldom Creek minus the Fourmile Lake watershed. Without any gage information for Seldom Creek, assumptions must be made about the additional water generated by this area. Since Seldom Creek is noted to only provide flow to Fourmile Creek intermittently, which is typically very large flows not seen in the early 1990s, Seldom Creek was assumed to not directly connect to Fourmile Creek for the months estimated in the 1990s. Since the majority of water in Fourmile Creek originates from springs in the upper headwater areas, the lower portion of the watershed is considered to produce minimal flow in comparison to the upper. The monthly total estimates generated from the USFS measurements were considered to be representative of what is produced by Fourmile Creek without the Fourmile Lake and Varney Creek watersheds.

During the 1960s daily gage records, the USGS collected daily streamflow measurements on Varney Creek and Fourmile Creek. These gages are both recorded during the same time period in the mid 1960s, between October 1964 and September 1967. These gages clearly illustrate how much water seeps subsurface on the alluvial valley floor. The flow in Varney Creek was measured just upstream of the confluence with Fourmile Creek. For several months, Varney Creek flow measured between 20-100 ac-ft, while the Fourmile Creek gage recorded no flow at all. By comparing the two records, losses in Varney Creek along the valley floor were estimated. In July 1965, the Varney Creek gage measured 113 ac-ft in total flow, and the Fourmile Creek gage measured only 1 ac-ft. Assuming Fourmile Creek above Varney Creek was otherwise dry that month, the losses in Varney Creek were estimated to be around 100 ac-ft per month. This information aided in generating natural flow estimates for the 1990s.

Monthly streamflow totals were naturalized by adding water excluded from gaged records to the gaged records. In the 1990s, the Varney Creek monthly total streamflow was estimated from USFS miscellaneous streamflow measurements. These totals, minus the estimated Varney Creek losses, were added to the Fourmile Creek monthly flow estimates. The remaining piece needed to naturalize streamflow was the water produced by the Fourmile Lake watershed.

The inflow to Fourmile Lake was estimated as monthly change in reservoir storage plus outflow. Since outflow to Fourmile Creek has not occurred over the last few years, and no documented outflows have been recorded, the only outflows included are those diverted into Cascade Canal. Diversion records for Cascade Canal out of Fourmile Lake are available from USBR back to June 1992. Prior to that 1992, the USGS maintained records for Cascade canal near Fourmile Lake intermittently since 1923. These diversions were added to change in reservoir storage, which were generated from end-of-month (EOM) reservoir contents. Reservoir EOM data have been collected intermittently for Fourmile Lake since 1923. A continuous record begins in September 1991 and is available through 2003. After adding diversions to change in storage, several resultant "inflow" values in the winter and early spring were still negative. These values are likely the result of losses to groundwater and evaporation.

In order to accurately naturalize gaged streamflow, negative numbers found by adding Cascade Canal diversions to the change in reservoir storage were replaced by zero values. When otherwise naturalizing streamflow after a dam is present, the evaporation losses would be estimated and added to the diversions and change in storage. Evaporation losses off Fourmile Lake were estimated to average 320 ac-ft per month, as long as evaporation rates are similar to those for Upper Klamath Lake. These evaporation losses were not used to naturalize lake inflows, because Fourmile Lake is a natural lake. Documentation of the lake's surface area prior to dam construction could not be found, so the post-dam evaporation losses were assumed to be similar to natural values. In the end, natural lake inflows were considered relatively equal to the change in Fourmile Lake storage plus diversions.

Natural flows were developed for Fourmile Creek during two time periods. To naturalize gaged data for Fourmile Creek, the estimated inflow to Fourmile Lake was added to monthly streamflow totals between October 1964 and September 1967 and estimated monthly totals between April 1992 and July 1996. Varney Creek flows were already reflected in the 1964-67 Fourmile gaged data, but the 1992-96 estimates did not reflect this additional water. Miscellaneous flow measurements on Varney Creek were collected by the USFS between April 1992 and July 1996, which enabled the development of monthly total estimates for Varney Creek. These estimates were generated by rescaling South Fork Rogue River (S.F. Rogue + S.F. Power Canal near Prospect) and Rogue River above Prospect gages based on concurrent measurements. The Varney Creek monthly flow estimates were decreased to reflect channel losses, which were estimated from the 1964-67 data, and then added to the 1992-1996 flows for Fourmile Creek. In total, natural monthly streamflow estimates for both the 1964-67 and 1992-96 time periods reflected the Varney Creek drainage, the Fourmile Lake headwaters, and the water produced by the in-between area.

The natural flow estimates from the 1990s still differ slightly from the 1960s data. The gage location of the 1960s Fourmile Creek data suggests some water was probably lost to ground water prior to being gaged near Rocky Point. Conversely, the gage location of the 1990s data reflects the water produced by the watershed more accurately for that time period. The flow of ground water through the alluvial valley bottom is likely to accrue towards Upper Klamath Lake even though some water may go subsurface upstream from the USGS gage location. In order to answer the ultimate question regarding how much water from Fourmile Creek would have provided inflow to the lake under natural conditions, the 1960s data were acknowledged to slightly underestimate the natural inflow to the lake from Fourmile Creek. The 1990s data were accepted as being more representative.

The monthly total natural flow estimates were then used to develop correlation equations with South Fork of the Rogue River. The Rogue River above Prospect was considered for correlation as well, but the South Fork Rogue River proved to reproduce expected values more accurately. This discovery is not surprising, since South Fork Rogue River lies closer to Fourmile Creek, immediately to the northwest with a common watershed boundary, and has similar geology and topography.

Correlation equations were developed using monthly natural streamflow totals. A general equation incorporating all available data was generated to represent most months, while some spring and summer months were further calibrated with season or month-specific equations. The flood event of December 1964-January 1965 and several subsequent runoff months were not included in these correlations, since the gaged streamflow values for Fourmile Creek during and after that event seem uncharacteristic for watersheds in the area. The cause for this departure can be attributed to either partial spill releases from Fourmile Lake, the reconnection of Seldom Creek during an extremely high flow event, or both.

The Fourmile Creek synthetic time series should be considered a rough estimate. Despite efforts to naturalize inflow to Fourmile Lake, the error incorporated in these data could not be determined. The derived natural flows for Fourmile Creek may be considered representative, since they reflect actual stream variability including zero values and significantly high flows. Although the extremely large flow events may not be represented with as much accuracy, the typical flows are effectively captured since the correlation equations used were based on typical flow regimes in two separate time periods.

<u>Denny Creek</u> – at Upper Klamath Lake

Denny Creek is located near the south end of Upper Klamath Lake and flows into Ball Bay. The watershed drains approximately 51 mi^2 and contains Aspen Lake. Only 17% of this watershed is within USFS land, with the majority within the Mountain Lakes Wilderness area. The remaining watershed area seems to be privately own, most likely by an individual owner. Despite similarities in geology between Denny Creek and adjacent watersheds, Denny Creek differs from most Wood River Valley watersheds in that the flow regime is not dominated by snowmelt runoff.

The streamflow hydrograph for Denny Creek is driven by the release of water from springs and winter precipitation, as seen in the peaking during winter months. Less snow accumulates in the headwaters of Denny Creek due to lower elevations. Because of this different flow regime, generating the synthetic natural time series for Denny Creek from a streamflow gage that was driven by snowmelt runoff was considered inappropriate. Streamflow gages for the area were analyzed for their dependence on winter precipitation, but no available gages were similar to Denny Creek. For lack of better data, the precipitation gage at Rocky Point was analyzed for relationships to streamflow in Denny Creek.

Instantaneous flow measurements were collected on Denny Creek by the USGS between September 1964 and October 1967. The USGS did not document whether any diversions occurred upstream of these measurements, so no diversions were assumed to have occurred. The Oregon Water Resources website shows one point of diversion upstream of the gage site, but the water right certificate connected to the point did not discuss or allow a diversion out of Denny Creek. This point of diversion was considered an error.

The USGS developed monthly total estimates for this time period (Hubbard, 1970), but these values were compared to redeveloped values to ensure accuracy. Redevelopment of monthly total streamflow estimates was completed using Varney Creek and Red Blanket Creek gaged data, and the results differed greatly from the USGS estimates, especially in low flow or baseflow months. The USGS estimates were considerably larger for these months. The redeveloped estimates were considered more accurate and were used in developing correlations to monthly precipitation data.

Precipitation is not considered to directly affect the flow in each month. The transit time over 58 mi^2 to the Denny Creek gage can be considerable, and groundwater recharge and resurfacing does not occur immediately. To represent these flow-affecting processes, precipitation totals were lagged over several months, with different percentages applied to each month, to find the effective precipitation value for each month. Ultimately, the best correlation to streamflow was found by lagging precipitation data 6 months, with 30% reaching the gage concurrently and the remaining 70% being lagged over the next 6 months. This effective percentage decreases each month, so the effective precipitation for each month is related to the precipitation from the previous 6 months. For example, the effective precipitation value for June is 30% of June's total precipitation, 21% of the May's precipitation, 15% of April's precipitation, and so on.

Correlations to streamflow were found between monthly effective precipitation values and monthly total streamflow estimates found between 1964 and 1967. Least-squares equations were found for effective precipitation values above and below 2.5 inches. The majority of effective precipitation values were below 2.5 inches, which was captured by a curvilinear correlation that recovered 86% of variability (r^2 value of 0.86).

The synthetic time series developed for Denny Creek is unique in that it depends solely on relationships between effective precipitation and streamflow between 1964 and 1967. The final time series sufficiently represents the streamflow in Denny Creek, since low-flow and extremely high flows were available in the gaged streamflow data, but this time series is not necessarily exact. More gaged information for Denny Creek would allow further correlation analysis to be completed. Also, collection of gage information on another nearby stream dominated by winter precipitation might also prove invaluable. Ultimately, the synthetic natural time series developed is representative for Denny Creek and adequately addresses the magnitude of inflow Denny Creek provides to Upper Klamath Lake.

Appendix 1-5X: Relevant hydraulic characteristics of the natural UKL and LKL

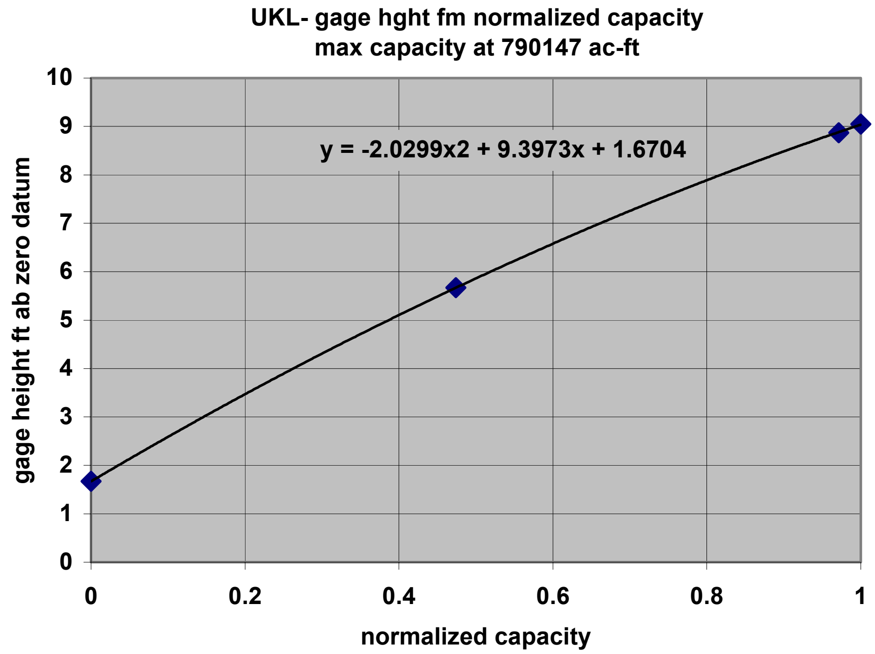
Upper Klamath Lake –

- *Area and capacity*

Capacity of the natural lake to store water is determined by the integration of changes in area with changes in depth. The change in area is easily determined as a function of depth where depth has been determined as the *gage height* for the corresponding water-surface elevation of the lake. To begin, at the minimum elevation for discharge from the natural lake, 4137.8 ft, the open-water surface area of the lake may be assumed to have evacuated the area of wetland marsh that is attendant to the lake. As the depth of the lake increases above this elevation to the estimated natural shore of the lake at 4141.8 ft, the inundation surface area of the storage prism also increases to the area indicated by the sum of the areas for the open-water surface and marsh. This is the area inundated by the lake at its stable water-surface elevation. The additional area inundated at the maximum observed water-surface elevation of the natural lake may also be integrated into the storage prism thereby allowing an estimate of the maximum natural capacity of the lake to store water. For the natural lake, then, the following were derived:

Elevation ft. above datum			Inundated area	Capacity
USGS	*USRS/BOR*	*gage*	acres	acre-feet
4136.0	4137.8	1.67	66,976	0
4140.0	4141.8	5.67	120,282	374,516
4143.2	4145.0	8.87	125,349	767,526
4143.38	4145.18	9.05	126,000	790,147

Derived changes in inundated area and capacity may each be expressed as a function of the indicated gage height noted above the established zero datum for the gage. Although such information provides a conceptually useful view of the lake, a water-budget simulation of the lake will require gage height to be derived inversely as a function of storage. For Upper Klamath Lake, the elevation of the zero datum for the gage was established as 4136.13 ft above USRS datum at installation of the gage, and the required factors for gage height and storage must be related to this elevation. Useable information about gage height of the water surface was, therefore, derived from storage by calculating gage height as a function of normalized capacity. Use of this curve would also provide information about the simulated elevation of the water surface of the natural lake. The resulting graph for this function is shown below.



- *Elevation and discharge*

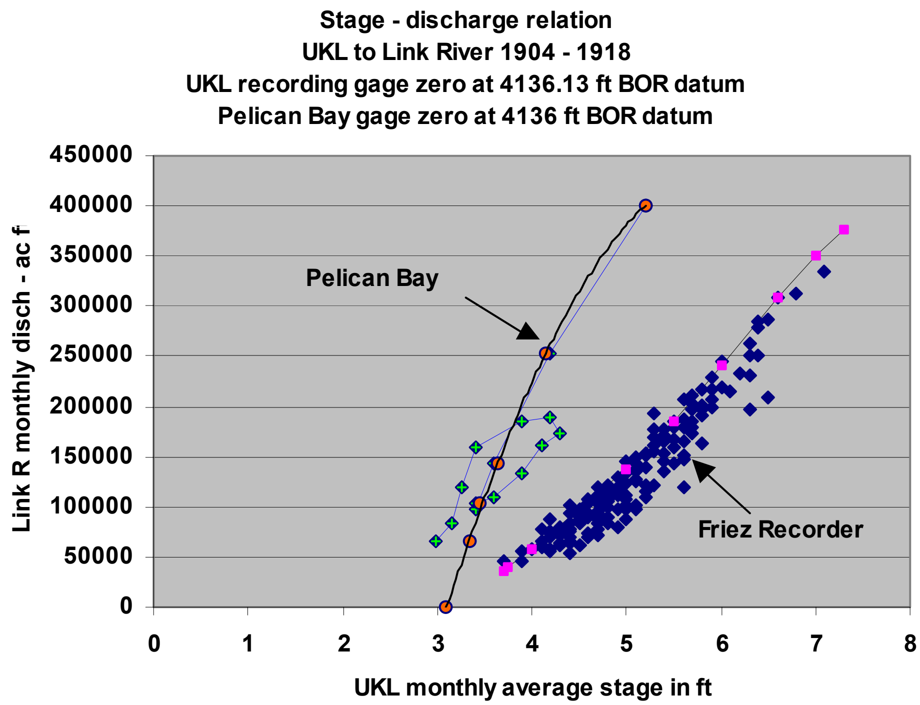
The discharge, or outfall, from the natural lake is dependent on the water-surface elevation of storage in the lake. Therefore, discharge from the natural lake may be directly related to gage height of the water surface. Given storage as a known factor in the water budget for the lake, the gage height, and hence discharge from the lake, may be calculated directly. To accomplish the discharge calculation, a discharge-rating curve must be derived for the natural lake based upon recorded monthly total discharge from the lake and the concurrently observed monthly average water-surface elevation. For the pre-dam period before the Link River crib dam was constructed, outfall from the lake was uncontrolled and dependent on the elevation of the water surface in the lake.

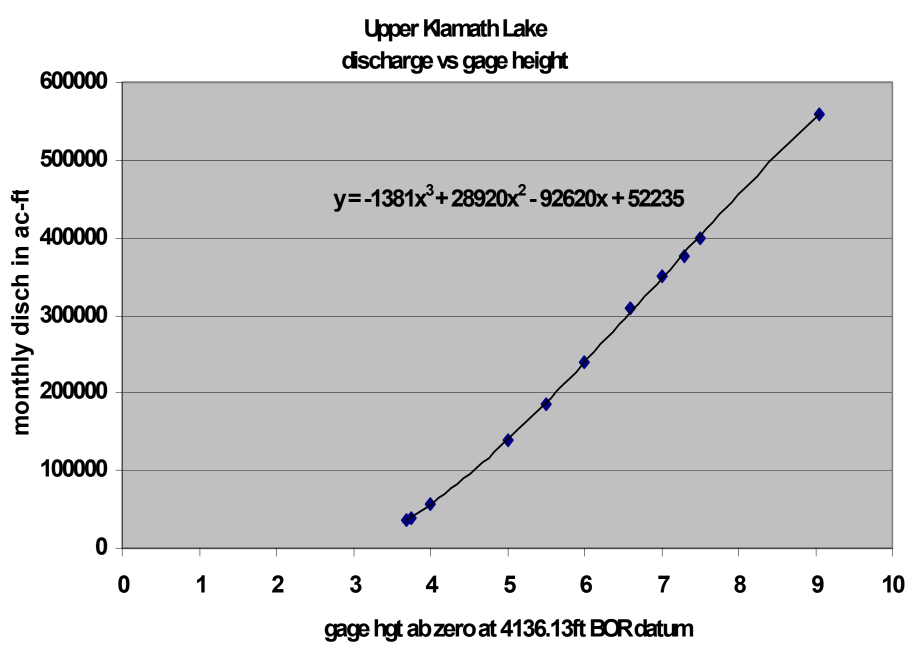
Evaluation of the rating curve was accomplished by noting the recorded monthly total discharge of the Link River, which was inclusive of diversions to the A canal, the Modoc power canal, and flow past the Link River gage. The monthly average water surface elevation of the lake was determined from records of the daily observed or daily recorded values at the gage above the outlet to the lake. Some of these data also included recorded water surface elevations at the Pelican Bay gage.

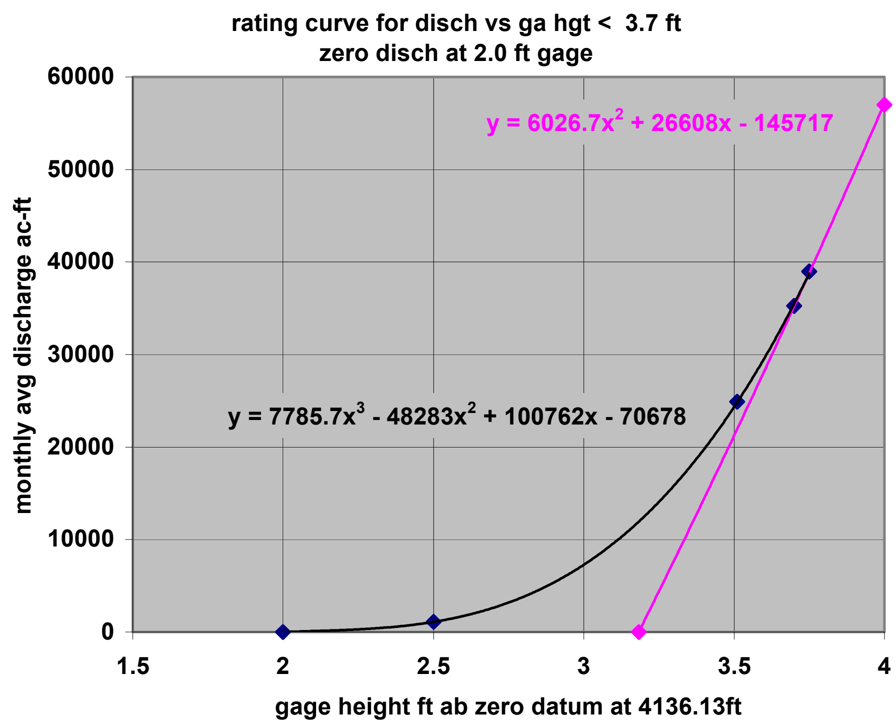
Problems with the Friez automatic recording gage near the outlet on Klamath Lake, however, had to be given special consideration in developing the rating curve. After initial installation of the Friez gage, the mechanism was not operating smoothly in response to changes in the water-surface elevation of the lake and posed problems in the maintenance of accurate records. This difficulty, which caused a series of ongoing maintenance problems with the gage, was evidently related to the Friez automatic register and the integrated pulley assembly for the recorder. The cause and record-artifacts of this difficulty are conceptually well understood. Further, up-valley winds were noted to decrease the outfall while maintaining the water-surface elevation of the lake. These two factors, problems with the recorder and winds on the lake, are commingled in the records for elevation of the water surface.

Separation of difficulties evident with the Friez recorder was facilitated by the absence of daily values in the record. For these missing days, generally every few days or at least once weekly, a gage-height reading was noted for the water surface elevation of the lake. Computer processing of these data allowed very representative estimates of the average water-surface elevation for each month that was considered in the record. Deviations from a regularly smooth trace for discharge plotted against gage height were evident by the smearing of the scatter of plotted points away from a limiting envelope along the left side of the scatter plot. Therefore, in developing the rating curve for outfall from the lake, the limiting envelope at the left side of the data scatter (shown below) was used as the definition of the rating curve. The lowest value on this curve was derived from the daily total flow on July 18, 1918, and several days preceding, when the record-lowest recorded daily water-surface elevation was noted for Upper Klamath Lake. Although up-valley winds occurring on this date caused flow from the lake to cease for a period of several hours on July 18, for the day and approximately six days prior, an average daily discharge was noted.

Closure of the curve to zero discharge was estimated by extension of the falling limb of the Pelican Bay monthly trace (left side of plot), and by extension of the curve along the limiting envelope of the outlet recording gage data. Both of these curves apparently achieve closure at about 3.183 feet gage. Because the outlet sill elevation would limit discharge to zero at 1.67 ft gage, the indication is that up-valley winds are holding back the lake and causing an adverse slope of the water surface against the wind. This condition is thereby limiting the outfall and giving an outfall depth of approximately 1.5 ft, more or less, for the water-surface elevation of the lake above the sill elevation of 4137.8 ft. This consequence would be consistent with the observed minimum discharge noted on July 18, 1918, and at other times noted in preceding years. Although not generally a common occurrence, the observation of zero discharge from the lake is, nonetheless, of significance to a simulation of the natural lake as indications regarding limiting outfall from the lake may be of importance to other considerations. However, an alternative rating curve for simulated water-surface elevations less than 3.7 ft gage was primarily used for the comparison of results with those given by a rating curve derived from recorded water-surface elevations, alone. Use of the alternative rating curve is intended to preclude underestimation of the outfall and maintain determination of representative results. The data plot and curves derived are illustrated below.


Stage - discharge relation
UKL to Link River 1904 - 1918
UKL recording gage zero at 4136.13 ft BOR datum
Pelican Bay gage zero at 4136 ft BOR datum
Link R monthly disch - ac f
UKL monthly average stage in ft
Pelican Bay
Friez Recorder
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
0 1 2 3 4 5 6 7 8


Upper Klamath Lake
discharge vs gage height
y = -1381x3 + 28920x2 - 92620x + 52235
monthly disch in ac-ft
gage hgt ab zero at 4136.13ft BOR datum
600000
500000
400000
300000
200000
100000
0
0 1 2 3 4 5 6 7 8 9 10



Estimated data establishing the curve along the limiting envelope were used directly for the generalized rating curve. Monthly average readings for gage height of the water surface at the outlet-recording gage are shown at the right of the graph, and from the gage at Pelican Bay, at the left. Of note is the discordance of readings for Pelican Bay with those of the outlet gage. Pelican Bay data provided no substantial information for the rating curve. Of note regarding the recording gage defined rating curve, is the flexure tending slightly downward above 6.0 ft gage. This flexure indicates that at the higher discharges indicated above 6.0 ft gage, the outlet channel is increasingly regulating the uncontrolled outfall from the lake.

For use in the simulation, the rating curve was extended to 9.05 ft gage to capture conditions evident during the maximum-recorded water surface elevation of the lake, which occurred in mid-April, 1904. Also, extension of the curve for an alternate rating curve below 3.7 ft gage, was forced to closure for zero flow at 2.0 ft gage, a seemingly representative value for zero discharge. Elements of each curve are shown below.

Lower Klamath Lake –

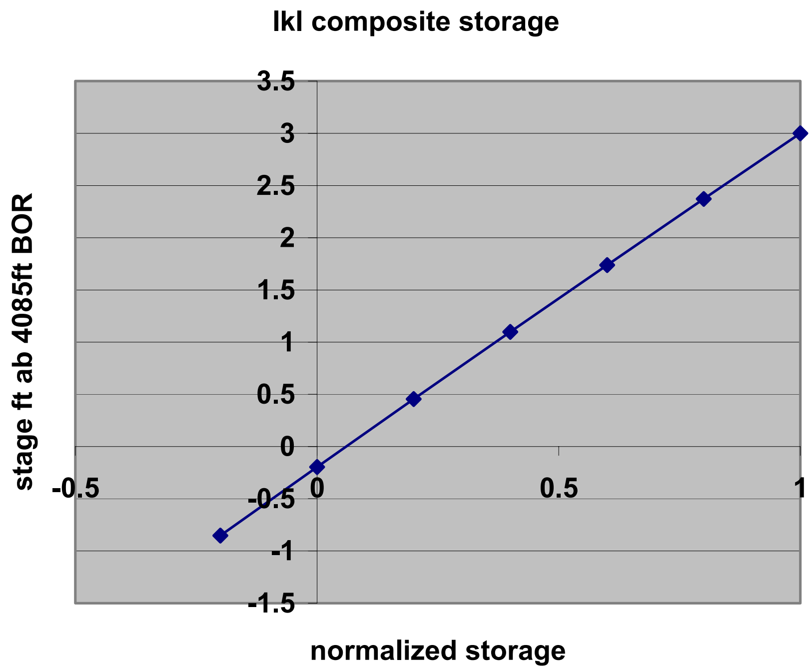
- *Area and capacity*

Capacity of the natural lake to store water is determined by the integration of changes in area with changes in depth. The change in area was conceptually determined as a function of depth where depth is directly related to the corresponding water-surface elevation of the lake. To begin, the datum for an outfall gage was defined indicating the reference elevation for an assumed static water surface elevation of the lake. Storage and discharge were referenced to this datum. The zero reference for this *gage* datum was at 4085 ft above the USRS datum. The minimum elevation for discharge from the natural lake was taken as 4083.1 ft above the USRS datum, the reef elevation at Keno. As the depth of the lake increases above 4085 ft to the estimated maximum water-surface elevation of the lake, the surface area of the storage prism also increases. This additional depth and inundated area may then be integrated to yield the volume of the storage prism thereby allowing an estimate of the maximum natural capacity of the lake to store water. The curve defining storage capacity was also extended for water-surface elevations below the zero gage elevation. This allowed the determination of storage for anticipated conditions simulating water-surface elevations below 4085 ft. For the natural lake, the following were conceptually derived:

LKL composite storage:

Lower Klamath Lake		Lost River Slough		Lake Ewauna		Composite LKL			
datum -	4084.8	datum -	4085	datum -	4085.1	datum -	4085		
lkl elevn	strg ac-ft	lkl elevn	strg ac-ft	lkl elevn	strg ac-ft	lkl elevn	strg ac-ft	stage	nrml strg
4084.8	0								
4085	16643.63	4085	0	4085.1	0	4085	16643.63	0	0.060169
4085.2	33301.72	4085.2	98.0778	4085.2	142.958	4085.2	33542.76	0.2	0.121262
4085.4	49974.28	4085.4	221.5432	4085.4	431.0823	4085.4	50626.9	0.4	0.183023
4085.6	66661.3	4085.6	370.3962	4085.6	722.1509	4085.6	67753.84	0.6	0.244939
4085.8	83362.78	4085.8	544.6368	4085.8	1016.164	4085.8	84923.58	0.8	0.30701
4086	100078.7	4086	744.265	4086	1313.121	4086	102136.1	1	0.369236
4086.2	116809.1	4086.2	969.2808	4086.2	1613.022	4086.2	119391.4	1.2	0.431616
4086.4	133554	4086.4	1219.684	4086.4	1915.868	4086.4	136689.5	1.4	0.494151
4086.6	150313.3	4086.6	1495.475	4086.6	2221.658	4086.6	154030.4	1.6	0.55684
4086.8	167087.1	4086.8	1796.654	4086.8	2530.392	4086.8	171414.1	1.8	0.619685
4087	183875.4	4087	2123.22	4087	2842.071	4087	188840.6	2	0.682684
4087.2	200678.1	4087.2	2475.174	4087.2	3156.693	4087.2	206309.9	2.2	0.745838
4087.4	217495.2	4087.4	2852.515	4087.4	3474.261	4087.4	223822	2.4	0.809146
4087.6	234326.9	4087.6	3255.244	4087.6	3794.772	4087.6	241376.9	2.6	0.872609
4087.8	251173	4087.8	3683.361	4087.8	4118.228	4087.8	258974.6	2.8	0.936227
4088	268033.5	4088	4136.865	4088	4444.627	4088	276615	3	1

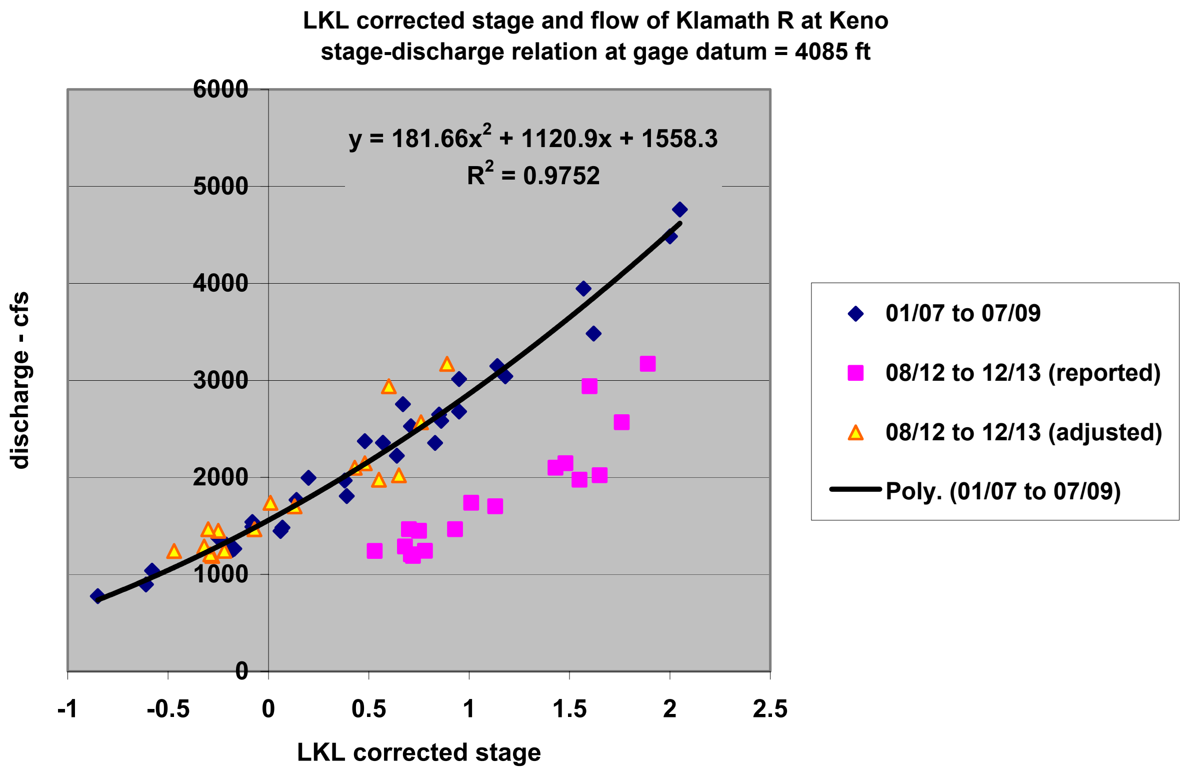
For the natural lake, derived changes in inundated area and capacity may each be expressed as a function of the indicated gage height, or lake stage, noted above the established zero datum for the gage. Although such information provides a conceptually useful view of the lake, a water-budget simulation of the lake required gage height to be derived inversely as a function of storage. For Lower Klamath Lake, published records of the water-surface elevation at the USRS maintained recording and staff gage may be referenced to the datum at 4085 ft. Required factors for gage height and storage must be related to this elevation. Useable information about gage height of the water surface was, therefore, derived from storage by calculating gage height, or lake stage, as a function of normalized capacity. Use of this curve would also provide information about the simulated elevation of the water surface of the natural lake. The resulting graph for this function is shown below.



- *Elevation and discharge: The Klamath River at Keno*

The discharge, or outfall, from the natural Lower Klamath Lake was conceptually related to the water-surface elevation of storage in the lake. Given storage as a known factor in the water budget for the lake, the gage height, and hence discharge from the lake, may be calculated directly. To accomplish the discharge calculation, a discharge-rating curve must be derived for the natural lake based upon recorded monthly total discharge from the lake and the concurrently observed monthly average water-surface elevation. Evaluation of the rating curve was accomplished by noting the recorded monthly total discharge of the Klamath River at Keno, and the concurrent monthly average water surface elevation determined from published records of the daily observed or daily-recorded water-surface gage height for the lake. Computer processing of the recorded daily elevation data allowed very representative estimates of the average water-surface elevation for each month that was considered in the record. In addition, discharge through the Lost River Slough must be considered and related to water-surface elevation of the lake.

For the Klamath River at Keno, the relationship for concurrent elevation of the water surface and discharge recorded at the gage is shown below. Published data for the gage readings from August, 1912, to December, 1913, were reported in reference to an erroneous datum for the gage. Correction of the reference datum allowed adjustment of these records to come into agreement with previous readings. Reported lake elevations from January, 1907, to July, 1909, were used to establish the rating curve for discharge used in the simulation, as shown in the plot, below. Closure of this rating curve for zero discharge is at 4082.9 ft above USRS datum. The actual limiting elevation of the reef at Keno is approximately 4083.1 ft.



- *Elevation and discharge: The Lost River Slough*

A natural overflow channel at the outlet of Lake Ewauna, the Lost River Slough, carried water out of the Klamath River drainage during higher-water storage events occurring in Lower Klamath Lake. During such events, Lake Ewauna was inundated and a continuous part of Lower Klamath Lake. Storage in Lower Klamath Lake resulting in a water-surface elevation greater than 4085 ft caused overflow into the Lost River Slough. This water would then flow into the closed basin of the Lost River, and into Tule Lake. To evaluate the nature and volume of flow through the Lost River Slough, an evaluation of the hydraulic performance of the stream channel would be required. This evaluation was necessary to derive a rating curve for discharge through the slough that could be used in the simulation of Lower Klamath Lake similar to the rating curve developed for flow from the lake at Keno. The flow characteristics of the Lost River Slough as the slough existed in the early part of the 20^{th} century were therefore studied using engineering and hydraulic computational methods. A rating curve for the 1905 Lost River Slough was developed using normal and critical flow depth calculations and standard backwater profiles based on the U.S. Army Corps of Engineers HEC-RAS River Analysis System Version 3.0.1 Mar 2001. The condition of the slough as evaluated would be the same that existing under natural conditions prior to construction of the dike closing the slough in 1890.

Over the length of the Lost River Slough, the channel elevation dropped from about 4085 feet at its entrance from the Klamath River, to an elevation of 4068.5 feet at its confluence with the Lost River. The slough would operate as a flowing channel only when there was sufficient flow and volume in the Klamath River and storage in Lower Klamath Lake. Under these conditions, the backwater effect caused by high elevation of the water surface in the Klamath River at the entrance to the Lost River Slough would cause water to begin flowing by gravity into the slough.

The Lost River Slough in the early part of the century was a meandering channel in a relatively wide, flat valley with potential islands that could develop and become submerged under high flow conditions. The slope of the channel bed is unknown, so only the average slope of the channel as a unit could be determined. The entire valley could convey flow since the elevation difference from side to side is potentially less than 2 feet. The entire left side (looking downstream) of the valley was potentially either a non-contributing flow area or a separate flow channel. The main flow channel was assumed to be comprised of rounded cobbles, gravels, and sand free of vegetation. The land outside of the main channel was estimated to be of alternately dry land or wet, marshy land comprising of some cobbles and gravels with grasses and other low, bushy vegetation.

The slope of the river was determined from topographic contours mapped by the USRS in 1905, as mentioned below. The limits of the Lost River Slough were delineated as that section between the Klamath River and the Lost River, or along the channel approximately 7 miles in length. The contours in that reach ranged from elevation 4085 to elevation 4082.5, so there is a fall of only about 2.5 feet over that length. The active channel was delineated but with only the 2.5 foot contours shown, the channel bottom elevation could not be determined. The average slope was determined using the known contours and the river distance between them. To estimate the *thalweg* (bed slope) an average slope from the highest contour to the lowest contour was used. This resulted in an average slope of 6.3928×10^{-5}, which was used for the entire reach of the river. The river distance was measured off the Department of the Interior, U.S. Reclamation Service, Topographic and Irrigation Map, Upper and Lower Klamath Projects, California – Oregon, 1905. The U.S. Geological Survey, Reclamation Service, Klamath Project, California – Oregon, General Progress Map, April 1905 was also used. The minimum stream channel elevation for computation purposes was calculated using the station and the average bed slope, located in the center of the channel with average slope up to the water line.

Six cross sections were developed along the Lost River Slough (designated Station 394+99.6, Station 332+86.4, Station 286+52.1, Station 277+06.2, Station 227+66.3 and Station 19+52.45). The first station is approximately 100 feet downstream from the elevation 4085 contour and the last station is upstream from the elevation 4082.5 contour. The locations for these cross sections were determined from the channel topography as potential flow control locations based on the width of the active channel at that location. Cross sections for the entire valley width were developed to include the entire range of flow depths with both the left and right edge extended to include all potential flow depths and with maximum elevations high enough to contain the expected flows. The cross sections were developed perpendicular to the expected flow channels not necessarily as a straight line across the valley. The active flow channel was developed from the plan for the low-flow conditions with the over-banks and ineffective-flow areas as additional areas for calculations.

The HEC-RAS file was developed based on the 6 main cross sections, a Manning's n roughness coefficient of 0.024 for the main flow channel, and a Manning's n roughness coefficient of 0.036 for the over-bank channel sections. The Manning's n was determined from photographs using USGS Water Supply Paper 1849, Roughness Characteristics of

Natural Channels, 1967. The main channel in the Lost River Slough was conceptualized as rounded cobbles and gravels free of vegetation. The over-bank areas were described as cobbles, gravels, weed and grass cover. Cobbles and gravel for the slough were most likely sourced from constricted channel areas such as that adjacent to Miller Hill. Some of the larger material in the channel could have been derived from terraces and prograded stream alluvium carried into the slough from the Klamath River or from Link River.

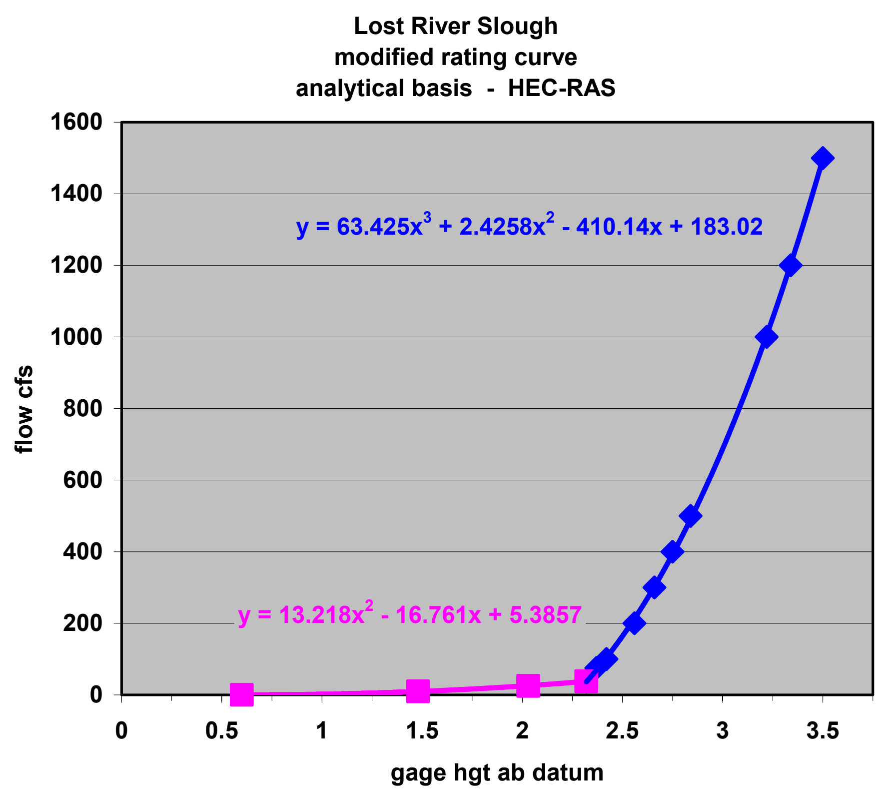
Fourteen flow discharges; 10-, 25-, 50-, 75-, 100-, 200-, 300-, 400-, 500-, 1000-, 1200-, 1500-, 2000-, and 3000-ft^3/s; were used for calculation purposes to determine the rating curve for each developed section. These flows were based on the need to define the boundaries of the lower flow ranges as well as an upper flow range. The HEC-RAS program was run for individual control sections, for short reaches with multiple sections, and for the entire reach. A rating curve was developed for critical and normal depth at each section for various flows. Additionally, a rating curve was developed for section 1 derived from the backwater curve based on a subcritical flow regime with either critical or normal depth at the downstream control point back upstream. This rating curve for section 1, with 6 control sections, was ultimately used to develop the *rating curve* for the Lost River Slough.

The developed Lost River Slough rating curve is a fixed-rating curve which was selected to simplify the computations. There is a hysteresis effect which occurs on the Lost River slough and affects the rating curve. The hysteresis effect is a very real hydraulic anomaly indicating the rating curve will have a lower stage for a given discharge when flow first occurs at the upstream end of the reach, but the stage rises for the same discharge as the valley becomes filled with more water. The selected rating curve begins at elevation 4085 based on that contour as the control elevation in the upper reach of the basin for the Lost River Slough. The flow control section for the Lost River Slough is initially located at station 394+99.61. As flow increases, the valley begins to accumulate storage and the control section moves downstream (hysteresis effect). However, due to the low slope of the river and valley, the large amount of ineffective flow area to the left (north) of the active channel, and the large amount of storage in the ineffective flow areas, the water surface elevations at Section 394+99.61 are impacted by backwater effects. The water surface elevation at Station 394+99.61 is that determined through a step-backwater method to account for the hydraulic losses in the system and control at the downstream sections. During the decreasing leg of the rating curve, the same elevation will have a lower discharge rating because the flow at that time is controlled by the downstream sections and the backwater effects caused by storage of water within the channel.

The rating curve used in the simulation was based the evaluation of all of the rating curves for the sections as applied with the resulting backwater effects to the entrance to the Lost River Slough at section 1, Station 394+99.6. The selected rating curve was based on control at section 4, Station 277+06.2 and not at the lowest section, Station 19+52.45, with no hysteresis effects. The conclusion to use this curve was based on the use of monthly time steps in the overall simulation with monthly averaged elevations and accompanying flows. The period of one month may be sufficient to fill the volume of contributing area in the Lost River Slough and cause the hysteresis effect. The storage volume accumulated in the Lost River Slough will create backwater and the lower discharges versus stage in the hysteresis will take effect. The use of Station 19+52.45 rating curve would create a higher water surface with lower flows into or out of the Lost River Slough.

The maximum flow though the Lost River Slough peaked at 114 ft^3/s; which correlates to an elevation 4087.4 and a stage of about 2.4 feet in the rating curve at Station 394+99.6 control section based on control at Station 277+06.2. If a control section further upstream had been used, this would over estimate the flow into the Lost River Slough on a monthly basis, but use of that control would be appropriate for shorter time periods. If a lower control section had been used that would have resulted in even lower flows into the Lost River Slough and would have been appropriate only if the duration and amounts of flow lasted many months. The use of this middle section is considered reasonable given the hysteresis effects and the time durations. The duration of flow into the Lost River Slough ranged from 1 month to a maximum of 6 months with 16 out of 40 flow periods lasting 1 month, 10 periods lasted 2 months and 9 periods lasted 3 months. The last 5 periods were 3 periods of 4 months, and 1 period each of 5- and 6-months.

The rating curve for the slough as used in the simulation, is shown below. This rating curve was slightly modified to accommodate smoothing the transition from the lower flow regime below elevations of about 4087.5 ft, to those higher, which is seen as a discontinuity in the curve at about 2.3 ft gage. The datum for the zero of this gage, as mentioned previously, is 4085 ft above USRS datum.



Appendix 1-6X: Ground-water balance for UKL –

The ground-water inflow to Upper Klamath Lake is a significant unmeasured component in the water budget for the lake. Determination of this inflow requires the measurement or estimation of all of the appreciable sources of inflow and outflow from the lake. Among these sources of inflow and outflow are precipitation to, and evaporation from, the lake surface, evapotranspiration from marshlands associated with the lake, and inflow from streams and other sources. For water years 1965 through 1967, Hubbard (1970) determined the ground-water flux to the lake by evaluating these inflow and outflow components in a water budget for the lake. The ground-water accrual to the lake was thereby determined as a residual in the water budget. In determination of the water budget for the lake, Hubbard had used an out-of-date area-capacity table for the reservoir. Further, the area table for inundated marsh incorrectly referenced USGS elevations to the BOR datum. Therefore, Hubbard's water budget was re-evaluated using the then current area-capacity table effective at the time of his study and a corrected table for marsh inundated area versus elevation referenced to the BOR elevation datum.

The water budget used by Hubbard is direct and conceptually well defined. The measured outflow from Upper Klamath Lake, as defined by the flow at the gage on Link River (plus the A Canal), is the result of all other inflow and outflow components to the lake. Therefore, the resulting measured outflow at the Link River gage is inclusive of all measured and unmeasured surface-water inflow to the lake, unmeasured ground-water inflow to the lake, changes in the storage of water within the lake, and other measured and unmeasured outflow from the lake. The measured inflow used by Hubbard included gaged inflow from the Williamson and Wood Rivers, generally unmeasured inflow estimated from temporary gage readings or field measurements of flow from several streams tributary to the lake including Denny Creek, Fourmile Creek, Rock Creek, and Sevenmile Creek, as well as inflow from several canals and drains including the Sevenmile Canal, Central Canal, and Modoc Point Canal drain, all of which were measured. The unmeasured inflow from precipitation was estimated from precipitation measured adjacent to the lake. Similarly, the unmeasured outflow from evaporation was estimated from pan evaporation measured at the lake. Precipitation and evaporation were applied to the estimated constant open water-surface area of the lake. Because the areal extent of inundated marshlands associated with the lake is known, transpiration of water from these marshlands was estimated using the Blaney-Criddle procedure. Hubbard considered the sum of marshland losses and evaporation from the open water surface of the lake to be evapotranspiration from the lake. Other measured outflow accounted in the water budget included irrigation pumpage from the lake.

The monthly summation of all of the elements in the water budget may be stated by the general form of the hydrologic equation, namely

$$i = o + \Delta s$$

where

i = inflow to Upper Klamath Lake
o = outflow from Upper Klamath Lake

and

Δs = change in storage of Upper Klamath Lake.

Because the equation does not balance using all of the measured or estimated components, the additional water required to balance the equation was determined by Hubbard to be due to unmeasured ground water accruing to the lake. He characterized this required additional inflow as the unmeasured inflow from springs and seeps that are below the water surface of the lake. Because Hubbard had accounted for all of the other significant factors regarding the water budget of the lake, except the inflow of ground water to the lake, the determination of this ground-water inflow was then easily derived by him as the residual required to balance the resulting outflow from the lake given the total evident in the water budget. This additional water required to balance the equation is termed, herein, the derived ground-water inflow, and is the same as that determined from the evaluation of Hubbard's water budget.

When this approach is used, the undetermined inflow, which is the ground-water inflow to the lake, accumulates all of the other errors appreciable to the other components the water budget. These errors include the errors associated with the measurement of inflow, errors in the measurement and estimation of precipitation and evaporation accruals to the lake, and errors in the gaging of storage within the lake. Additional errors are attributable to the application of the Blaney-Criddle method and the estimation of evaporation from the open water surface of the lake in the determination of total evapotranspiration from the lake. As these errors are propagated through the water budget, they will cumulatively cancel or be reinforced through accumulation on the residual element needed to balance the equation. This is an unavoidable consequence as the solution for the required element, the estimated ground-water inflow, is derived through a backward-solving process. There is, however, no other feasible approach to determine the ground-water inflow to the lake.

To obtain useful information for the undepleted flow study, the evaluation of Hubbard's water budget required an examination of the derived monthly ground-water inflow versus the monthly average gage height of the reservoir. Because Upper Klamath Lake would capture discharge from the regional aquifer that is producing the unmeasured ground-water inflow to the lake, if the inflow of ground water to the lake is responsive to lake stage, which is directly related to the elevation of the water surface of the lake, then consideration of this relationship would be of useful to the study. This is because Upper Klamath Lake, as a natural water body, would have experienced an unregulated lake stage that is different than that of the now regulated reservoir. Given the limited data available in Hubbard's study, the task presented is to determine if relationships can be developed from these data that are representative of real processes and present the reasonable ability to explain the variability that is observed in the derived ground-water inflow.

Evaulation of Hubbard's water budget for UKL –

Because the study completed by Hubbard contained potentially critical errors regarding elevation relations for storage and area of UKL, correction of these errors and implementation of corrections would be necessary. Therefore, several background sources of supporting information were used in the evaluation of the water budget Hubbard developed for UKL. Specific data elements reviewed for accuracy in Hubbard's work included verification of the capacity table used by the USGS for the water budget and correction of the table, verification of the marshland inundation table developed by Hubbard for use in the water budget and correction of that table, and verification of evaporation data used by the USGS. Use of the correct capacity table was critical to the evaluation of the change in storage, Δs, in the water budget. Use of the correct elevation datum in referencing inundated marshland area was critical to the evaluation of marsh consumptive uses as implemented in the water budget. Because both a floating pan and land pan were used to estimate lake evaporation, verification and validation of these data sources was seen as helpful in understanding the application of such data in the water budget. For the water budget as published, the following were noted:

1) At the time of Hubbard's study, the USGS was using an out-dated capacity table that had been developed in 1923 for Upper Klamath Lake. The table current at the time of Hubbard's study had been developed from a bathymetric survey of UKL completed by the BOR in 1953. The BOR table incorporated inundated areas determined from preliminary editions of the new USGS 15' topographic surveys of the area, on file BOR plane-table surveys, and extensive aerial photography of the lake and associated irrigated areas on file in the Klamath Area Office. The 1953 table was also republished in 1974 by BOR as then current, thereby indicating the 1953 table was current at the time of Hubbard's study and should have been in current use by the USGS. Appropriate elements in Hubbard's water budget were therefore corrected with a digital version of the 1953 table.

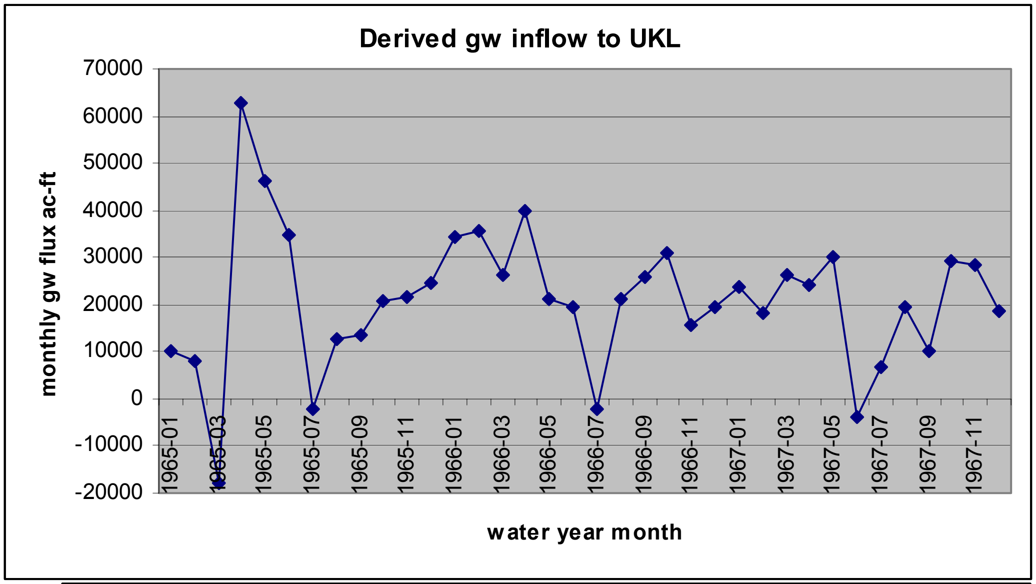
2) The marshland inundation table used by Hubbard evidently referenced BOR data for areas below the water surface of the lake, but determined inundated areas above the water surface by using the very same published USGS topographic surveys that were used in 1953 by the Bureau in preliminary form. Therefore, water-surface areas in this table are referenced to the *BOR elevation datum* for areas below the water surface of the lake, but referenced the *USGS elevation datum* for elevations of inundated areas that were above the near-average water surface of the lake. Consequently, the area of inundation was posted to elevations that, in effect, referenced a blended datum. The elevation data for Hubbard's inundated marsh area table were corrected by matching total water-surface areas given Hubbard's table with those in the 1953 BOR table and cross referencing the elevations to the correct datum. Correction of the inundated marsh area table was validated by subtracting the inundated marsh area from the corresponding total water surface area given in a specially extended version of the BOR 1953 area table. The remainder in the subtraction, 66,500 acres, is the open-water surface area that was used by Hubbard.

3) Evaporation data could be generally verified for land-pan evaporation but could not be verified for floating-pan evaporation. Land-pan data was indicated as sourced from the Klamath Falls Agricultural Station at Kingsley Field, and was validated as being from that source. Floating-pan data was indicated as that collected by Pacific Power and Light from the floating pan near the outlet of UKL. Floating-pan data could not be verified, or validated, as sourced from PP&L through cross-checking with similar data records on file in the Klamath Area Office. No immediate explanation of these differences was evident.

Interpretive evaluation of calculated results –

Results of the evaluation of Hubbard's water budget are presented initially for a recalculation of the published work with the implementation of the correct capacity table for computation of Δs, the change in storage, but with no other corrections. Because the published work is generally available, revision of the calculations opens accessibility to the sequential computation process and understanding of results in Hubbard's water budget. This initial recalculation, as such, is termed herein the *new* evaluation. Other corrections and modifications are presented in the discussion section that follows. Successive changes and significance of errors inherent in the water budget are also easily examined.

An examination of the monthly time series for derived ground-water inflow and monthly average water-surface elevation, given as the monthly average gage height for UKL, seems to provide some information regarding the behaviour of the ground-water system. The time-series plots, shown below, have plotting areas aligned to show the simultaneous relationship between these two data elements. Notable is the apparent nature of the ground-water inflow in relation the changes in the elevation of the water surface. Apparently, as the lake stage increases, ground-water inflow to the lake declines. A decline in lake stage causes the opposite effect. Evidently, UKL captures significant ground-water discharge from the regional aquifer. Therefore, the decline in ground-water flow to the lake could be caused by the elevation of the water surface of the lake balancing the driving head for ground-water flow from the regional aquifer. Another reasonable cause is the influx of water into bank storage as the lake stage increases, and reflux from bank storage as the lake stage decreases. As will be shown, both of these processes acting together, head balancing and bank storage, conceptually explain the opposing behaviour of ground-water accruals to changes in elevation of the water surface of the lake.



Derived gw inflow to UKL
monthly gw flux ac-ft
water year month
70000
60000
50000
40000
30000
20000
10000
0
-10000
-20000
1965-01
1965-03
1965-05
1965-07
1965-09
1965-11
1966-01
1966-03
1966-05
1966-07
1966-09
1966-11
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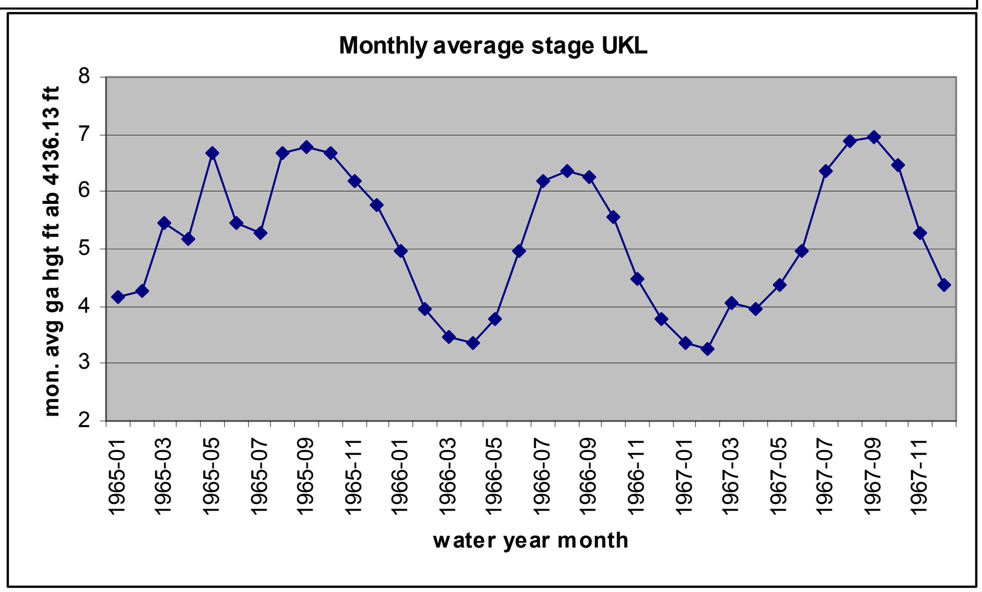
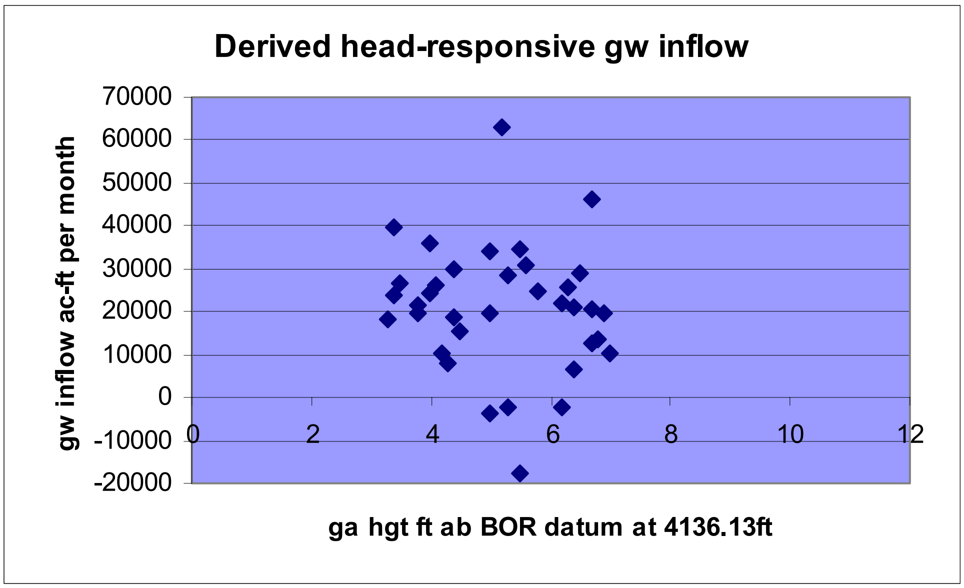
1967-07
1967-09
1967-11

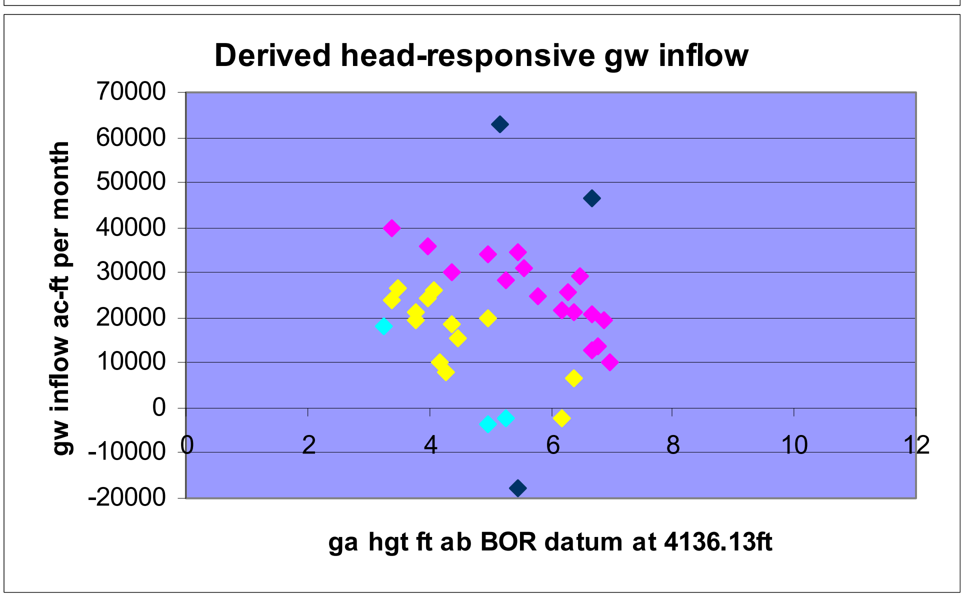


Monthly average stage UKL
mon. avg ga hgt ft ab 4136.13 ft
water year month
8
7
6
5
4
3
2
1965-01
1965-03
1965-05
1965-07
1965-09
1965-11
1966-01
1966-03
1966-05
1966-07
1966-09
1966-11
1967-01
1967-03
1967-05
1967-07
1967-09
1967-11

An examination of the derived ground-water inflow to the lake, plotted as a function of the measured monthly average gage-height recorded for the water surface of the lake (below, upper panel), shows an apparent random scatter of plotted values. These monthly values range from an accrual of more than 60,000 ac-ft to a loss of nearly 20,000 ac-ft. Although no correlated behaviour between the plotted variables is immediately apparent in the scatter plot, suspected evidence of correlated behaviour is likely evident within the scatter.

Data in the scatter plot seem to form two inversely variant groupings that may be interpreted in relation to lake stage and their time-ordered sequence (below, lower panel). Therefore, the points within the time-ordered sequence of the monthly time series were color coded by their group association as evident in the scatter plot. These associations are shown in the color-coded table on the next page. Although a definite pattern then becomes evident, the groupings must be interpretively separated without any resulting commingling of points.





Points associated with each data grouping, designated as right (magenta) or left (yellow), form essentially continuous monthly runs as evidenced within the time series. Corresponding magenta colored cells in the table indicate data elements interpreted to be associated with the right grouping. Corresponding yellow cells are those associated with the left grouping. The dark-teal coded cells near the top of the table mark the flood of the winter of 1965, and are anomalous. Other apparently anomalous values are color coded as turquoise. Note that the sequence, whether color-coded magneta, or yellow, seems occasionally broken near the end of its run.

Time associations are interpretively evident within the continuous run segments associated with each of the two designated primary groupings. Magenta cells appear to be principally associated with late spring through summer changes in lake elevation. Yellow cells seem principally associated with late summer through early-to-late winter changes in lake elevation. During each of these times the lake is undergoing different interactive processes with the ground-water system. During the spring and early summer, the lake is receiving runoff from spring snowmelt and the elevation of the water surface of the lake is increasing. This increase in water-surface elevation would suppress the discharge of ground water captured from the regional aquifer that is providing flow into the lake, and would cause an influx of water to bank storage. These processes are consistent with the magenta grouping. As the snowmelt inflow declines in the mid-summer, the continuous release of water from storage in the lake causes the elevation of the water surface to decline and would, thereby, increase the inflow of ground water from the regional aquifer and cause the reflux of water to the lake from bank storage. This process would occur early in the summer and could extend into the fall. Because water-surface elevations of the lake during the mid-summer through fall usually seem to remain stable in comparison to the increases noted during spring snowmelt, fluctuations in the lake during mid-summer through fall would be interactive with the storage and release of water from bank storage. These processes are consistent with the yellow grouping.

gw infl data developed fm Hubbard (1970)

index	avg stage	gage hgt	gw infl
1964-12	4140.9	4.77	spgs/seeps
1965-01	4140.3	4.17	10353.23
1965-02	4140.4	4.27	8037.0188
1965-03	4141.6	5.47	-17676.97
1965-04	4141.3	5.17	62917.857
1965-05	4142.8	6.67	46367.696
1965-06	4141.6	5.47	34751.679
1965-07	4141.4	5.27	-2089.104
1965-08	4142.8	6.67	12693.632
1965-09	4142.9	6.77	13571.291
1965-10	4142.8	6.67	20792.488
1965-11	4142.3	6.17	21754.124
1965-12	4141.9	5.77	24719.788
1966-01	4141.1	4.97	34257.48
1966-02	4140.1	3.97	35796.815
1966-03	4139.6	3.47	26399.533
1966-04	4139.5	3.37	39800
1966-05	4139.9	3.77	21356.992
1966-06	4141.1	4.97	19685.251
1966-07	4142.3	6.17	-2146.883
1966-08	4142.5	6.37	21205.072
1966-09	4142.4	6.27	25853.133
1966-10	4141.7	5.57	31042.599
1966-11	4140.6	4.47	15530.315
1966-12	4139.9	3.77	19570.626
1967-01	4139.5	3.37	23860.772
1967-02	4139.4	3.27	18097.618
1967-03	4140.2	4.07	26258.341
1967-04	4140.1	3.97	24205.532
1967-05	4140.5	4.37	30020.383
1967-06	4141.1	4.97	-3713.919
1967-07	4142.5	6.37	6579.9325
1967-08	4143	6.87	19453.625
1967-09	4143.1	6.97	10204.095
1967-10	4142.6	6.47	29080.865
1967-11	4141.4	5.27	28279.611
1967-12	4140.5	4.37	18731.073

Conceptualization and modeling of the ground-water interactions –

Use of this interpretive assessment in the natural flow study requires the formulation of simple and consistent rules by which the conceptual elements in the ground-water system are understood to interact. Because information about this system is limited, these rules must have as their bases reasonably simple conceptualizations of the possible interactions of the lake with the ground-water system, as explained in the section above. This formulation of rules is the first step in developing a simple rule-based model for the head-responsive performance of the ground-water system associated with Upper Klamath Lake. This interpretive assessment, and the formulation and application of the rules, requires an understanding of 1) the limitations caused by errors in Hubbard's water budget, 2) the limitations regarding derivable information from Hubbard's water budget of only three years length, and 3) *the need to remain less specific and more general in the application of operational rules that describe performance of the system*. Errors in the water budget are due to imperfect measurements. The application of rules that are too specific will cause consequential and reproducible errors in the estimated ground-water inflow. Hence, applicable rules that are overly specific may simply reproduce the results of Hubbard's water budget without providing a reasonable basis for conceptually understanding the general interactions within system. The three-year time applicable to the water budget is a serious limitation regarding derivable information from the provided data. A longer time span for Hubbard's water budget would have allowed refinement in the determination of results by improving the resolution of the errors and the estimation of their consequences. Therefore, errors will also result from the limitations inherent in the information derivable from the Hubbard's water budget.

As a general conceptual rule for Upper Klamath Lake, increases in elevation of the water surface of the reservoir will increase the balance of head driving ground water into the lake and will also cause, thereby, the influx of water to bank storage. This effectively decreases discharge from the regional aquifer and causes the loss of water from the lake into bank storage. A decrease in elevation of the water surface will produce exactly the opposite effect. Therefore, the two conceptual elements (or regimes) of the ground-water system that are identified with the lake include 1) the head-dependent discharge of ground water captured from a regional aquifer of considerable areal extent, and 2) the interaction of the lake with bank storage. An examination of the groupings in the data plot showing derived ground-water inflow versus the monthly average gage-height of the water surface expresses aspects of each of these two conceptual elements.

The mathematical description of this process is given by the generalized equation

$$y = y_0 - y_0*(h/x_0) + c_0 - (h - x_b)*\phi$$

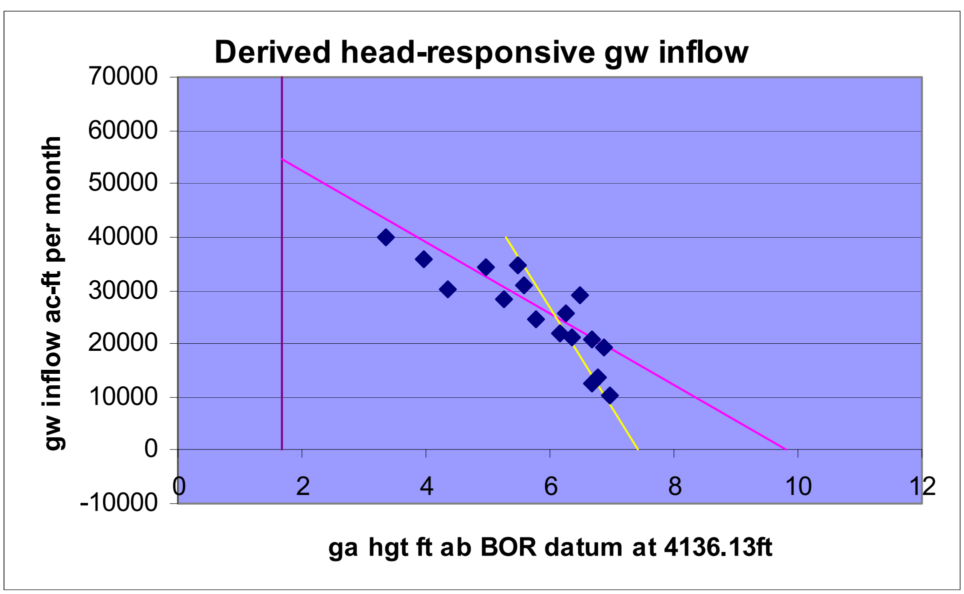
where

y_0 = selected y-axis intercept, acre feet (fixed)
h = gage height of the water surface in feet (variable)
x_0 = selected x-axis intercept, feet (fixed)
c_0 = constant
x_b = selected flux balance line intercept, feet, for bank storage (fixed)
ϕ = flux rate, to/from bank storage, in ac-ft/mon/ft change in h (fixed)

and the result

y = ground-water flux to the lake, ac-ft/month.

The application of this equation assumes the fixed terms are static and free from error. This assumption is easily modified to accommodate variability in each of the fixed terms given a time series related to the indicated change for each fixed term. The relationship of each of these conceptual elements is shown relative to the right (magenta) grouping which has been extracted and is shown with solid blue diamonds within the plot below. The lines show the response functions associated with the regional aquifer, in magenta, and bank storage, in yellow. Each line is defined by the data group having qualities that may be interpretively evaluated and applied inclusively to the entire set of data. The head response associated with the regional aquifer, as given by the magenta line, is typified by the right group. However, the interactive response associated with bank storage, as given by the yellow line, is uniquely typified by the *left* (yellow) data group, as will be explained below. The dark red vertical line at h = 1.67 ft gage, is the sill-limiting elevation of the water surface of the lake.



Calculation of the ground-water inflow for conditions that are defined by the right grouping is given conditionally. The conditional sequence for a water-surface stage greater than 4.5ft gage is defined as

if $h_i > h_{i-1}$

then

$y_i = y_0 - y_0*(h_i/x_0) + c_0 - (h_i - x_b)*\phi$ (yellow line)

else

if $h_i \leq h_{i-1}$

then

$y_i = y_0 - y_0*(h_i/x_0) + c_0$ (magenta line)

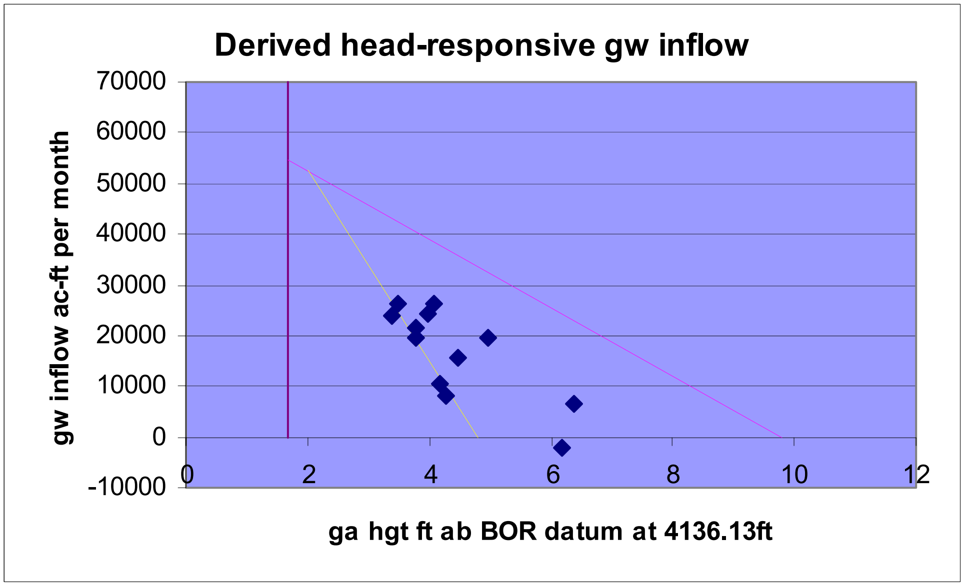
where, in the conditional sequence,

h_i = average gage height during the current month
h_{i-1} = average gage height during the previous month

and

y_i = calculated ground-water accrual for the current month.

The yellow-line expression for the interpretively defined interactive response with bank storage appears to be well defined in association with the left (yellow) data grouping, and seems to have a significant relationship the magenta line, as shown below. The relationship of each of these conceptual elements is shown relative to the left (yellow) grouping which has been extracted and is shown in blue within the plot below. Notable is the intersection of the yellow line with the magenta line *near the sill-limiting elevation of the water surface* at 1.67 ft gage. The representative gage-height for this intersection was chosen at x_b = 2.0 ft gage. As explained previously, this line also forms the basis for the same interactive response defined for the right grouping. For the right grouping, x_b has been chosen as x_b = 6.1 ft gage.



Calculation of the ground-water inflow for conditions that are defined by the left grouping is given conditionally. The condition for less than 4.5ft gage is defined as

$$y_i = y_0 - y_0*(h_i/x_0) + c_0 - (h_i - x_b)*\phi \quad \text{(yellow line).}$$

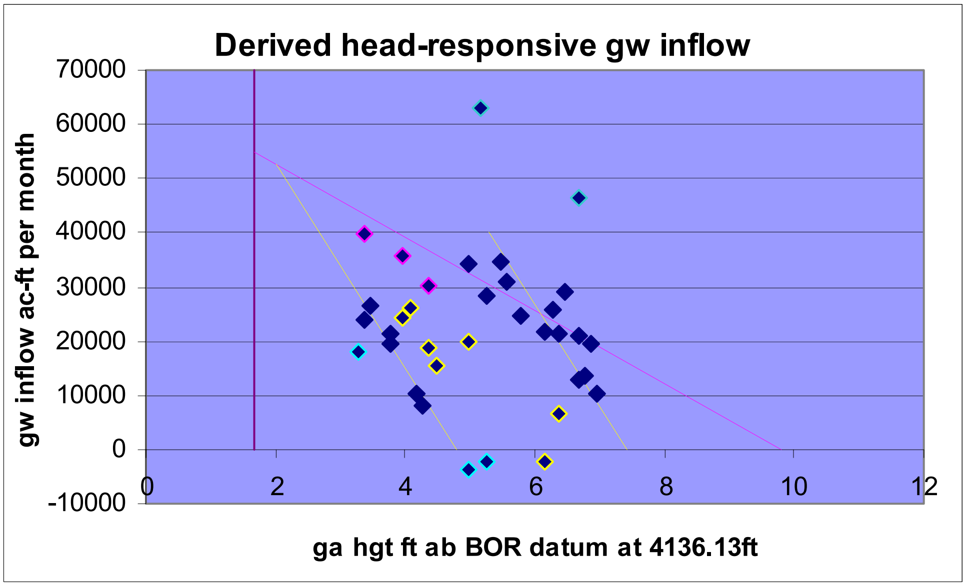
Fixed values used in the equations defining the ground-water flux to Upper Klamath Lake are defined as follows:

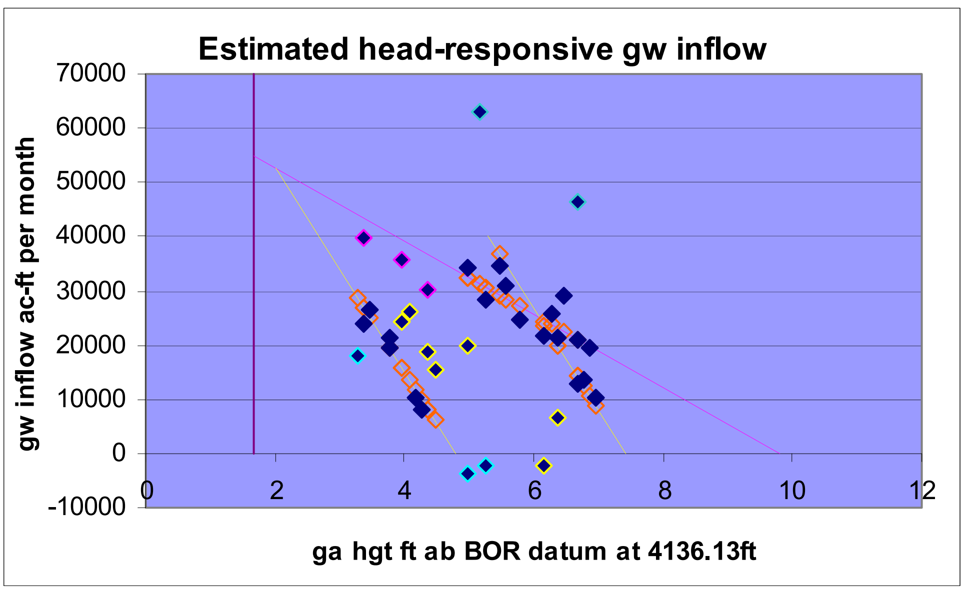
	$h \leq 4.5$ ft gage	$h > 4.5$ ft gage
y_0	66,000 ac-ft	66,000 ac-ft
x_0	9.8 ft gage	9.8 ft gage
c_0	0.0 ac-ft	0.0 ac-ft
x_b	2.0 ft gage	6.1 ft gage
ϕ	12,000 ac-ft/mo/ft	12,000 ac-ft/mo/ft

The application of fixed values that are consistent allows the definition of a head-response model that is consistent and straightforward. These elements in the conceptualization of the ground-water interactions with Upper Klamath Lake are then easily modified or adjusted to accommodate their application to the lake as a natural, unregulated water body. However, the application of these rules must be checked against the water budget to determine if the results for estimated ground-water inflow would be representative. Further, the consequence of errors must be evaluated as those errors will affect the derived ground-water inflow expressed in the water budget.

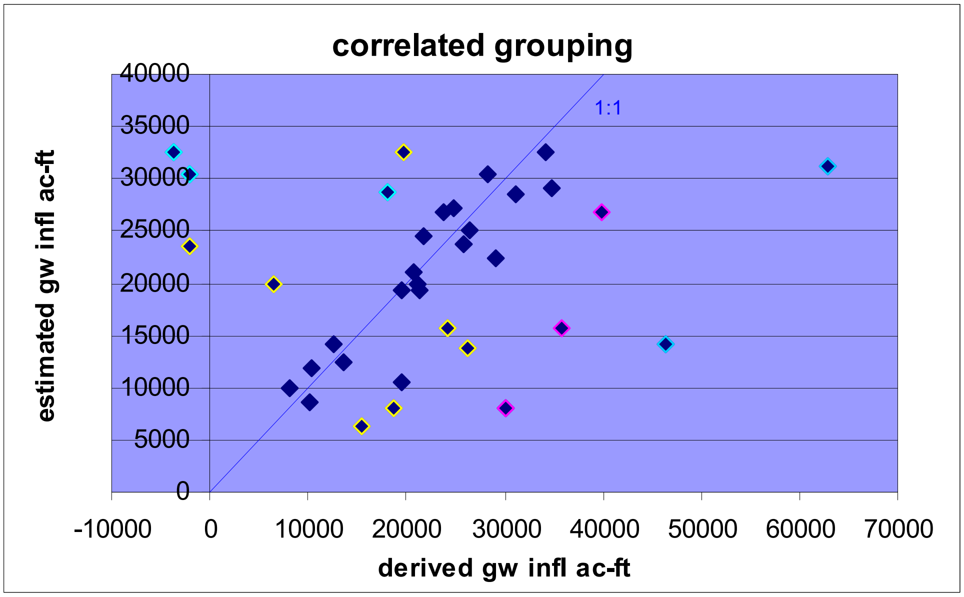
An assessment of the plotted data and the linear expressions for ground-water flux to Upper Klamath Lake allows suspected errors in these data to be interpretively identified. The assessment process is based on a comparison of the lines for the estimated head-responsive ground-water inflow with the values derived using the water budget procedure of Hubbard. The results of this comparison illuminate some of the variability noticed in the plotted points, shown below (upper panel), in relation to the head response functions. The two isolated, highest inflow points (darker turquoise highlight) are due to a flood event in 1965 and are suspect regarding total ground-water flux to the lake. Hubbard indicates these values are due to unmeasured surface-water inflow that is effectively left as part of the residual in the water budget. Other points that are highlighted have been interpretively identified with seasonal conditions that may be responsible for errors in the water budget. The turquoise highlighted points are associated with the same turquoise colored anomalous values identified earlier, and are related to ground-water flux values derived in the winter and spring. The cause of these errors could be due, in Hubbard's water budget, to undetermined, or inaccurately determined, transpiration and evaporation losses from the lake. Yellow highlighted points are typically associated with the winter. These values would result from losses that have been estimated as too large, if associated with the left (yellow) grouping, or too small, if associated with the right (magenta) grouping. Further, three points associated with the right (magenta) grouping have been problematic in assessment of error due to limitations in the application of rules for simulating ground-water inflow to the lake. However, any of the noted errors could be due to a combination of other conditions affecting the lake as well as errors in the 1923 and 1953 area-capacity tables.

Among the interesting aspects regarding these errors is the presence of values that appear to be collinear in association with the left data grouping. Yellow and turquoise highlighted points appear to fall along alignments that are parallel to the determined head-response function for the left grouping (leftmost yellow line). In the application of the rules for calculating the estimated ground-water inflow to Upper Klamath Lake, the procedural correction of these errors becomes evident. As shown in the lower panel, below, the *model-estimated* values for the given set of data are shown as open-orange diamonds plotted on the same style plot as that shown above. The bases for calculation of the estimated values are in implementation of operational rules (as explained previously) that were conceptually developed given the time-ordered sequence of monthly average water-surface elevations noted from October, 1964 through September, 1967.
This operational implementation of rules effectively forms the rule-base model that is desired.

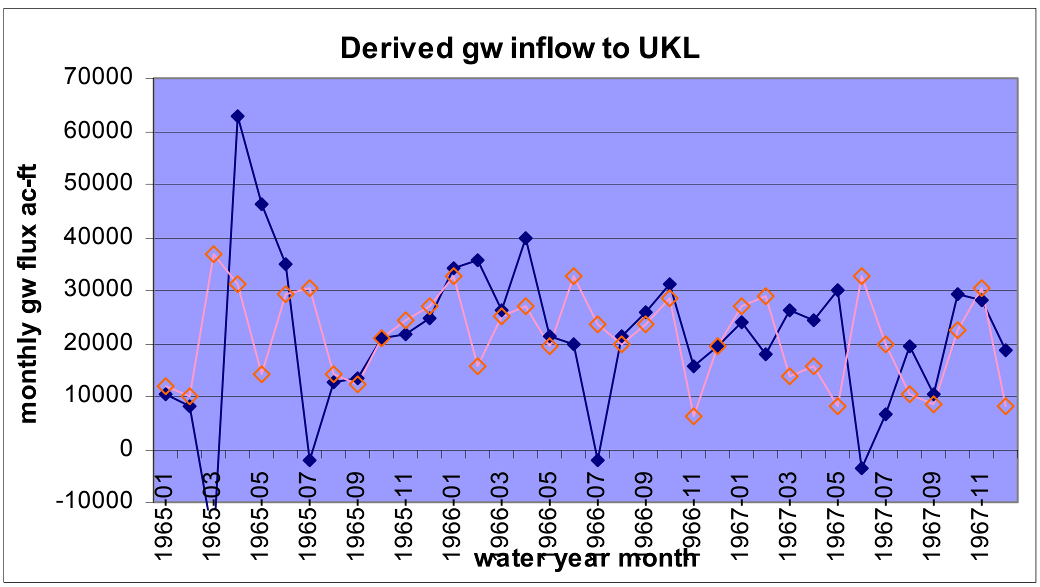

Derived head-responsive gw inflow
gw inflow ac-ft per month
70000
60000
50000
40000
30000
20000
10000
0
-10000
0
2
4
6
8
10
12
ga hgt ft ab BOR datum at 4136.13ft


Estimated head-responsive gw inflow
gw inflow ac-ft per month
70000
60000
50000
40000
30000
20000
10000
0
-10000
0
2
4
6
8
10
12
ga hgt ft ab BOR datum at 4136.13ft

Evaluation of the modeled result is accomplished through a correlation grouping comparison and through an overlay of the resulting rule-calculated time-series on a hydrograph of the derived ground-water inflow. The correlated grouping plot shows how well these rule-calculated values agree with the derived ground-water inflow to the lake. The derived values interpreted as erroneous in the plot above, are similarly highlighted in the correlation grouping that is plotted below. The less specific rules that were applied in the assessment result in a few values that tend to drift to the right of the line of correlation. Correction of this drift may be obtained through application of more specific operational rules, or through the correction of functional errors. However, the results may not be representative if the implementation of such rules mimics errors in the water budget. As is seen in the lower panel for derived ground-water inflow to Upper Klamath Lake, the application of the rules developed for the head-responsive conceptualized system as explained herein, mimics well the monthly time series for ground-water inflow to the lake. The resulting simulated ground-water inflow (orange-diamond line) is consistent in comparison with the excessively high or low values that are derived using Hubbard's approach for the water budget for the lake. To a large degree, through the application of interpretively-based rules for assessing the ground-water flux to Upper Klamath Lake, estimated values agree well with those derived through the water budget used by Hubbard.



correlated grouping
estimated gw infl ac-ft
derived gw infl ac-ft
1:1
40000
35000
30000
25000
20000
15000
10000
5000
0
-10000
0
10000
20000
30000
40000
50000
60000
70000



Derived gw inflow to UKL
monthly gw flux ac-ft
water year month
70000
60000
50000
40000
30000
20000
10000
0
-10000
1965-01
1965-03
1965-05
1965-07
1965-09
1965-11
1966-01
1966-03
1966-05
1966-07
1966-09
1966-11
1967-01
1967-03
1967-05
1967-07
1967-09
1967-11

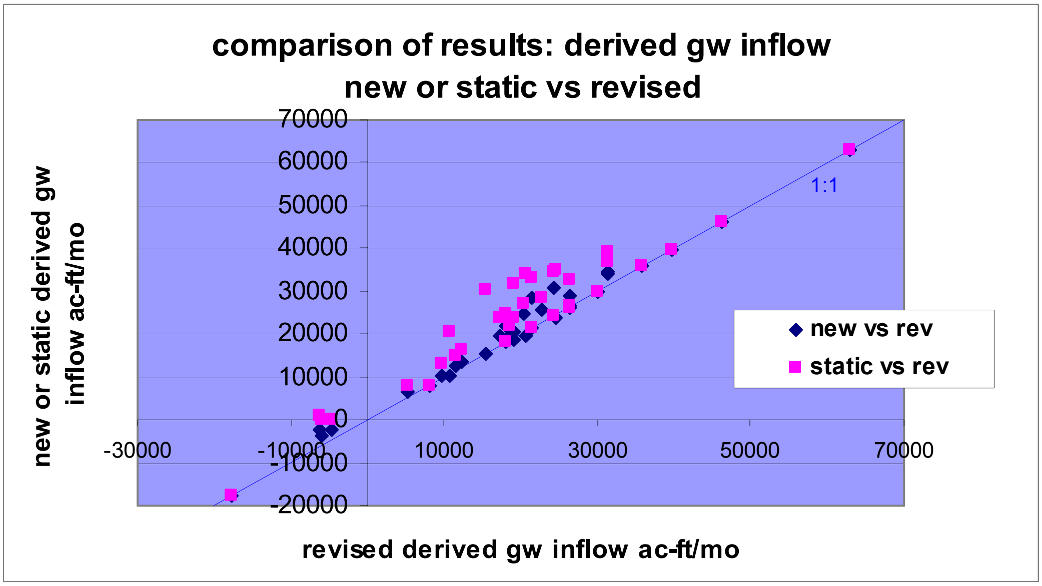
Discussion –

Results of the recalculation and *new* evaluation of Hubbard's water budget indicate the derived ground- water inflow to UKL averaged approximately 252,000 ac-ft per year for water years 1965 through 1967. This result is virtually identical with the original determination of Hubbard. Results of the *related modeling for the new evaluation* indicate an estimated average ground-water inflow of approximately 254,000 ac-ft per year for these years. These results, however, are based on the implementation of an inundated marsh area table that incorrectly referenced USGS elevations to the BOR datum, even though the month-to-month change in storage was determined using the then-current 1953 capacity table for the reservoir.

As mentioned previously, the calculation procedure for the *new* evaluation followed exactly the same basic scheme evident in the published water budget for Upper Klamath Lake. The scheme adopted by Hubbard calculated marshland losses based on the inundated area of marsh given the average water-surface elevation of the lake for any given month. Therefore, Hubbard's water budget was revised and recalculated again using an inundated marsh area table that <u>correctly referenced</u> lake-surface elevations to the BOR datum. Presentation of these results is termed herein, the *revised* evaluation. Results of this *revised* and recalculated water budget again use Hubbard's basic scheme but with both the correct capacity and datum-corrected inundated-marsh tables. The *revised* evaluation indicates the derived ground-water inflow averaged approximately 234,400 ac-ft per year for these three years. Results of the modeling for the revised evaluation indicate that for these same years, the estimated ground-water inflow averaged about 234,600 ac-ft per year.

With the help of the Portland office of the USGS, Hubbard's file notes were reviewed regarding the supporting data and calculation procedures he used in the published water budget for Upper Klamath Lake. Within those notes were calculation sheets indicating an evaluation of the water budget based on a static marsh area that effectively remained constant in the calculation of marshland losses associated with the lake. This static area procedure for the calculation of marshland losses is identical to that used for the marshland-loss calculations in the natural flow study. Therefore, results of the *revised* water budget were recalculated using Hubbard's determined static marsh area, herein termed the *static* evaluation. The results indicate the average ground-water inflow was approximately 292,300 ac-ft per year for these three years. Results of the modeling for the *static* evaluation indicate that for these same years, the average ground-water inflow was approximately 297,700 ac-ft per year. As mentioned below, the *static* evaluation using a constant marsh area does not provide a plausibly representative indication of the head-dependent ground-water inflow to Upper Klamath Lake.

To examine the significance of changes in the calculation procedure by implementation of each scheme, calculated results of the basic water budget for the *new* and *static* evaluations were compared to those for the *revised* evaluation. The *revised* evaluation used corrected tables for both marshland-inundated area and capacity. Because that revision correctly implemented tables that were that were not used in Hubbard's originally published water budget, the *revised* evaluation therefore establishes an appropriate baseline for these comparisons. As shown below, results that closely compare with the *revised* evaluation will fall closely along the 1:1 line of correspondence, while results that depart from the *revised* evaluation will not fall along line of correspondence. An examination of this correspondence indicates results from the *new* evaluation, which uses the correct capacity table, agree very closely with those given by the *revised* evaluation, which uses both the correct capacity table and corrected table for inundated marsh area. Results given by the *static* evaluation show the greatest departure.



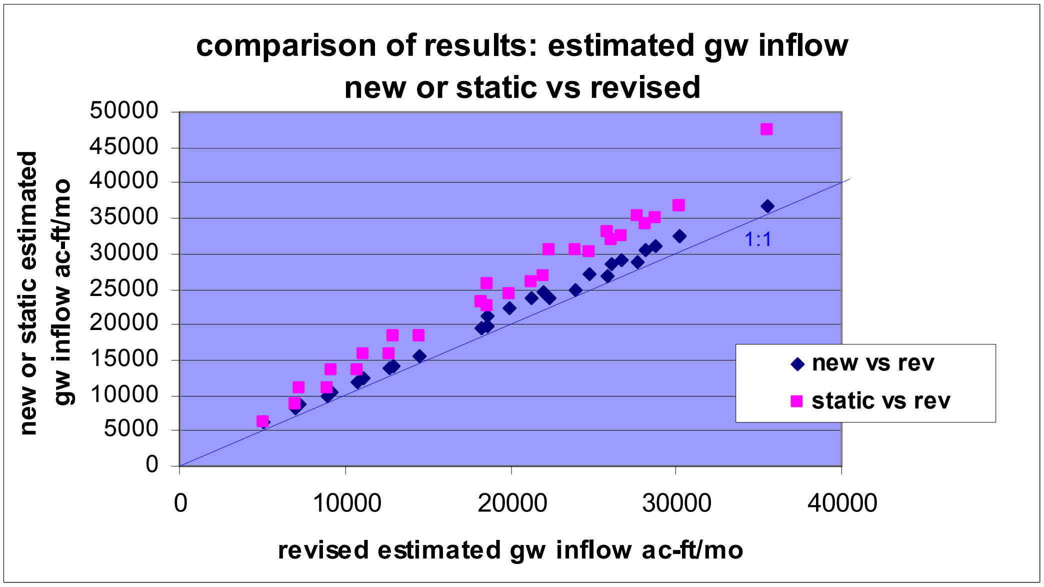
Interpretation of these results indicates the following plausible outcome:

1) The *static* evaluation, which is based on an unchanging marshland area for calculation of marsh transpiration lost from the lake, provides a derived ground-water inflow that is generally too large because marshlands above the inundation area of the reservoir are incurring depletions from bank storage that was previously filled from lake storage. Such depletions are not significantly interactive with the head-responsive flow of ground water to the reservoir. The previously filled bank storage has already been accounted in the water budget.

2) The *new* evaluation using the correct capacity table provides a derived ground-water inflow that is somewhat too large due to errors in the inundated-area table used to evaluate marshland transpiration lost from the lake. The results, however, more closely approximate those achieved by the *revised* evaluation using correct area and capacity tables.

3) Results of the *revised* evaluation provide a derived ground-water inflow that is representative because water transpired from the marsh is calculated as that coming directly from in-place storage in the reservoir. Depletions of in-place storage would affect the water surface elevation of the lake and therefore directly affect the head-responsive inflow of ground water.

A similar comparison may be made for the results of modeling ground-water inflow for each evaluation. The correlated grouping plots for these models show very little overall difference from that shown for the *new* evaluation, in the preceding section, above. For each evaluation, comparison of the modeled ground-water inflow hydrograph overlaid on the derived ground-water inflow hydrograph also shows very little overall difference from that shown for the *new* evaluation, in the preceding section, above. Principal differences noted are those shown in the comparisons of calculated results for derived ground-water inflow, as shown in the comparison of results, just above. A similar plot for estimated results from each modeling evaluation is shown below. As can be seen, the ground-water inflow estimated by the model for the *new* evaluation, which implemented only the correct capacity table, shows the closest agreement with the estimated ground-water inflow by the model for the *revised* evaluation.



Appendix 2-1X: Documentation of ukl.lkl_simulation, an Excel spreadsheet

General form –

Computation of the water budget for a water body, such as a natural lake or reservoir, must follow the hydrologic equation, namely,

$$i = o + \Delta s$$

where

i = inflow to the water body

o = outflow from the water body

and

Δs = change in storage of the water body.

Although the equation is a general statement that may be used to solve for one of the elements if two are known, the equation is also a statement regarding the water-balance of a natural lake. All equation elements must cause the equation to balance. Categorized parts of each element may be used in a general progression of calculations intended to achieve this balance. Each element may be a conceptualized as part of a calculation subsequence ending in a net result for the desired quantity. For instance, precipitation on the lake surface is an inflow, but may be accounted to evaporation resulting in net evaporation, the sum of the monthly evaporation rate and the precipitation noted for that month. *Net evaporation is accounted as part of the outflow but includes precipitation* to the lake *which is part of the inflow*. *The sum of inflow to the lake, and losses,* such as evaporation, and marshland net et that is attendant to the lake, *forms the net inflow*. As such, *the net inflow to the lake is the characterization of* i in the equation above, *and may be used in place of that quantity*. This method of element characterization is used because 1) *stable quantities are desired in calculations* using the hydrologic equation, 2) the net inflow is that part of the total inflow that has been depleted by in-place outflow processes, such as evaporation, and 3) *the important quantity needed* to calculate monthly discharge from the lake, or outfall o, *is the storage within the lake*. *The estimate of storage* resulting from the net inflow *is usable as a stable monthly quantity* that may be used in other calculations. The calculation process for discharge requires an estimate of storage to calculate gage height of the water surface so that discharge from the lake, or outfall, may be estimated. As such, the discharge is a characterization for Δs, the change in storage given in the equation above, and is also a stable quantity. Hence, the abstracted solvable quantity has become Δs, the change in storage. Now the residual storage may be calculated as $s - \Delta s$, where s is the storage and Δs has been substituted as the outfall, or o, the now characterized physical outflow from the lake. The residual storage then becomes a calculation seed allowing storage in the next succeeding month to be estimated as the sum of the residual storage just determined for the current month and net inflow that will be determined for the next succeeding month. This general conceptualization has been applied in development of the water-budget simulation for UKL and LKL.

The general form of the computations used in the spreadsheet follows the description given in Part 3 of the report. Hydraulic elements are described in Appendix 1-5X. Descriptive elements are presented graphically in the **notes** tab of the spreadsheet. Other aspects are calculated or adjusted on tabs for **ukl_gw.flux** and **evap.notes**. Inflow from the west side of the Wood River Valley is given on tab **west.side_infl**. All values generally used in the computations are in acre-feet unless indicated otherwise. Descriptive documentation of the **calculations** tab is given below. The reported precision of the values given on the spreadsheets generally exceeds the reliable accuracy of the estimates.

Upper Klamath Lake and Link R. gage

Inflow –

On the **calculations** tab, inflow is presented in cols A through P. The column heading *index* simply indicates the water year and month for the given row on sheet. The column heading *value* gives the element being used in the water budget at the time-step for the designated *index*. These conventions are generally applicable across the sheet. Notes and comments are as indicated.

Cols A through K indicate tributary inflow to UKL from the Williamson R., Wood R., Crooked Cr., and west-side streams that head on the east flank of the Cascades and flow into the Wood R. Valley or Pelican Bay extension of UKL.

Col L contains the unmeasured ground-water inflow attributable to relationships evident in Hubbard's water budget for UKL. The calculation is threaded from col H in the tab **ukl_gw.flux**. Essentially, the unmeasured ground-water inflow is calculated based on the average lake stage estimated during the month being considered. This inflow is added to the estimated UKL storage that results from the net inflow from all other sources.

Col M contains unmeasured ground-water inflow that is tributary to streams flowing into the lake from other sources.

Cols O and P give the summation of the total natural inflow in acre-feet (O) and average monthly flow in cfs (P).

Cols Q through X indicate losses that deplete the natural inflow to UKL.

Col R indicates the net evaporation loss from the lake as derived on tab **evap.notes**.

Col U indicates the net et from marsh associated with the lake.

Col W indicates the summation of losses due to net evap and net marsh et given in cols R and U.

Cols Y and Z indicate the net inflow, which is col O less col W.

Cols AA through AG are not used in the interim version.

Col AH indicates the storage. The starting storage given in AH5 is the surrogate of residual storage used to initially seed the process. The quantity in AH5 is calculated from the starting elevation given in AA3. This starting elevation may be changed to initiate a different starting storage and evaluate results. With the cell AH6, the quantity is calculated from the respective values threaded from col B6 of tab **ukl_gw.flux** and given in col L6 of the **calculations** tab.

Col AI indicates the normalized capacity occupied by storage as a fraction of the maximum capacity indicated in AB3.

Col AJ indicates the gage height of the lake stage in feet derived as a function of normalized capacity given in AI. The equation for the stage given as a function or normalized capacity is indicated beginning in AI3 within the highlighted green area, above.

Col AK indicates the discharge, or outfall, calculated from the respective value in AJ. This is the estimated natural flow at the Link River gage.

Col AL indicates the residual storage calculated as the difference of respective values in AH and AK.

Col AM is the monthly average discharge in cfs of the value given in AK.

Col AN is the water-surface elevation in ft above the BOR datum derived from the gage height given in col AJ. The gage zero elevation datum is 4136.13 ft BOR.

Col AN ends the calculations for UKL and Link R. gage.

<u>Lower Klamath Lake and Keno gage</u>

Col AO begins the calculation sequence for LKL

Col AP indicates marsh evapotranspiration associated with LKL

Cols AX to BA indicate evaporation from the cylinder portion of the open-water surface. The cylinder portion of the open-water surface area is partitioned into subareas that are referenced the nearest weather station for which evaporation has been calculated. The Hargreaves evaporation for each subarea (or partition) has been calculated for the Klamath Falls 2 SSW and Merrill weather stations, as indicated. Cylinder open-water surface area related to each station for that calculation is given in Col AZ rows 3 and 4. Total cylinder open-water surface evaporation is given in Col BA.

Cols BC and BD are Link R inflow in ac-ft/mo and avg cfs/mo as indicated.

Col BE indicates Quinton's note on Hall's measurement of ground-water inflow from springs which was indicated by Quinton as "more than 100 cfs."

Cols BF thru BM indicate calculated elements for the prism open-water surface area, also called the overflow surface area. These overflow surface areas are calculated using equations given on the **notes** tab for each respective overflow area related to Lower Klamath Lake (lkl), the Lost River Slough (lrs), or Lake Ewauna (le). Hargreaves evaporation for each partition is as indicated.

Col BM indicates the total evaporation for the overflow surface area.

Col BO indicates the total loss given by the sum of the marsh evaportranspiration and open-water surface area evaporation.

Col BP indicates the net inflow to LKL.
Col BQ indicates the storage in the LKL complex. Starting stage is indicated in BQ4, and may be changed to initiate different starting conditions and evaluate results.

Cols BR and BS indicate the normalized storage and inversely calculated stage in ft for calculation of the outfall at Keno.

Col BT indicates the calculated outfall in cfs at Keno for the stage given in Col BS. This value is calculated using the stage-discharge relation for Keno given on line 3 in the similarly color-coded area above the column. The outfall is converted to ac-ft as shown in Col BU.

Col BV indicates the calculated overflow through the Lost River Slough. This value is calculated using the stage-discharge relation for the Lost River Slough given for specific conditions indicated by the equations on lines 3 and 4 in the similar color-coded area above the column. The overflow discharge is converted to ac-ft as shown in Col BW.

Col BX indicates the residual storage in ac-ft.

Col BY indicates the elevation of the water surface in ft referenced to the USRS datum.

Some abbreviations and contracted words that are used –

evap - evaporation
gw - ground water
ows, owsa - open-water surface, open-water surface area
overfl sa - overflow surface area (the area inundated on mud flats, shorelines, and banks)
storg, strge - storage

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